TECHNICAL REPORT
NATICK/TR-99/026

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RADAPPERTIZED BEEF PRODUCTS, THEIR TECHNOLOGY AND QUALITY

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June 1999

Final Report
February - November 1970

Approved for Public Release; Distribution Unlimited

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1999	FINAL February - November 1970

4. TITLE AND SUBTITLE

RADAPPERTIZED BEEF PRODUCTS, THEIR TECHNOLOGY AND QUALITY

5. FUNDING NUMBERS

C 8AB81A
N 3122

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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Natick, MA 01760-5018

8. PERFORMING ORGANIZATION REPORT NUMBER

NATICK/TR-99/026

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report describes many experiments conducted with different irradiated beef products, including ground beef, beef steaks, restructured beef rounds and corned beef. Various irradiation temperatures and doses were studied. The effects of additives including different phosphates, nitrates and nitrite and texture soy protein were studied. Extensive sensory and consumer panel results are included. Chemical analyses are presented. Color and texture measurements are also included.

14. SUBJECT TERMS

RADAPPERTIZED MEAT, BEEF, IRRADIATION, ACCEPTANCE, CONSUMER PREFERENCES, QUALITY, IRRADIATED FOOD, RADAPPERTIZATION, FLAVOR, SENSORY ANALYSIS

15. NUMBER OF PAGES 55

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18 298-102

USAPPC V1.00

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PREFACE

The data for this report was collected by investigators from the US Army, Natick Research and Development Center, Food Irradiation Division during the 1970s It is being published now because the Army has expressed an interest in irradiation sterilized meat products, Loveridge, 1994. The data is relevant.

The report describes experiments done with irradiated beef products including ground beef, beef steaks, restructured beef rounds and corned beef. Many of the studies include extensive sensory and consumer panel results. Chemical analyses are presented. Color and texture measurements were made. Various irradiation temperatures and doses were studied. The effects of additives including different phosphates, nitrates and nitrite, salt and textured soy protein were studied.

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RADAPPERTIZED BEEF PRODUCTS, THEIR TECHNOLOGY AND QUALITY

INTRODUCTION

Beef is the most important meat in the United States. Its per capita consumption is over one half of the total red meats consumed by the American public; this applies to the civilian population as well as the military. Therefore, development of shelf-stable, highly acceptable irradiated beef was and continues to be of paramount importance to the U.S. Army's Radiation Preservation of Food Program. Secondary effects of irradiation - particularly at sterilizing doses of 30 to 60 kGy - can cause undesirable chemical and physical changes in meats which affect flavor, odor, texture, color and ultimately, consumer acceptance of the meats. Changes in the flavor are the most pronounced effects of meat irradiation and beef is the most sensitive in this respect. Irradiation conditions were studied to mitigate secondary reatcns.

This paper will discuss a number of different individual studies that were done with various irradiated beef products. The products studied included beef loins, beef rounds, loin steaks, ground beef and corned beef.

Some of the effects studied were:

A. Effect of irradiation temperature
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BACKGROUND/LITERATURE RESEARCH

Irradiation at subzero temperatures has been shown to decrease the radiation-induced changes in the sensory characteristics and chemical composition of beef when compared to irradiating in the non-frozen state. Data are available on decreases in radiation-induced changes which were obtained by irradiating beef at extremely low temperatures (-80 to -185 ^{o}C). The temperature range of +20 to -185 ^{o}C was investigated, the purpose being to find the optimum temperature for the irradiation of beef. To accomplish this purpose, experimental work was carried out to determine differences in the sensory characteristics and preference ratings of irradiated beef.

The present investigators were not the first to recognize that the irradiation of meats in the frozen state is a promising method for reducing the deleterious effects of ionizing radiation at high processing doses. Several investigators have reported that the adverse quality changes, such as off-flavor and off-odor formation during irradiation, can be reduced or eliminated by irradiating foods at temperatures in the range of -80 to -196 ^{o}C. (Coleby, et al. 1961) reported that raw beef and pork irradiated with 50 kGy at -75 ^{o}C were preferred to the meats irradiated with 20 kGy at

+18 °C. The authors reported further that raw beef irradiated at various temperature levels showed little protection from irradiation damage within the range of 0 to +18 °C; a rapid increase in protection from 0 to -20 °C; and smaller gains at temperature levels between -20 and -196 °C.

Snyder (1961) found that off-odor formation in beef steaks was reduced to threshold values when irradiated in liquid nitrogen (-196 °C). Harlan, et al. (1967) and Kauffman et al. (1969) observed a linear decrease in the intensity of irradiation off-flavors of beef steaks as temperatures of irradiation were successively decreased from +20 to -196 °C. Wadsworth and Shults (1966) found that beef irradiated at -196 °C was significantly preferred to beef irradiated at -50 °C by both trained technological and consumer panels. Harlan (1967) reported that meat items irradiated in liquid nitrogen (-196 °C) were comparable in their organoleptic characteristics with nonirradiated controls. Shults and Wierbicki (1974) reported a significant difference at the 5% confidence level in preference scores for beef loin samples irradiated at -50 and - 185 °C but no differences were observed among the samples irradiated at -80, -120 and -185 °C. The sensory scores were all at acceptable levels.

Although irradiation at subzero temperatures is encouraging for reducing the adverse effects of irradiation on acceptance, it does not solve all the problems encountered in the irradiation of beef. Grecz, et al. (1965) using D_{10} values for clostridia spores, reported that the lethal effects of gamma rays decreased by 47% in ground beef when irradiated at -196 ° C as compared with 0°C. As a consequence, the cans inoculated with 5×10^5 spores of C. botulinum 33A required 9 kGy more irradiation at -196 °C than at 0 °C to inactivate the spores. In another paper, Grecz, et al. (1971) reported that the resistance of C. botulinum 33A spores to irradiation in cooked beef increased with the decrease of temperature during irradiation in the range from +65 to -196 °C. This resistance increase followed equally well a quadratic, exponential or linear best-fit plot. Therefore, as the temperature during irradiation is decreased, the total dose must be increased to insure sterility of the products.

The chemistry of the flavor changes has not been completely elucidated, although it has been under active investigation. It has been generally acknowledged that flavor changes are primarily due to the formation of volatile compounds from lipids (Merritt, et al., 1966; Dubravcic and Nawar, 1968; Champagne and Nawar, 1969) and protein precursors (Merritt, 1966; Merritt, et al., 1967a). There has been a continuing study of these changes (Josephson and Merritt, et al., 1972), so that the nature of the chemical changes which occur due to irradiation is now very well known. The understanding of the basic chemistry has been achieved mainly by qualitative analysis of the trace volatile components by combined gas chromatography-mass spectroscopy (GC-MS) techniques (Merritt, 1970, 1972). Later developments employing a digital computer system to GC-MS output now provide accurate quantitative data as well (Merritt, et al., 1974). The precise determination of the variation in the amounts of components with various processing conditions such as dose or temperature now permits the correlation of chemical changes with sensory observations.

The results of these studies have led to developments in processing techniques so that contemporary meat products have very little so-called irradiation flavor and are wholly acceptable consumer items.

The previously reported research has utilized whole cuts of beef to reduce biological variations found among the different muscles. This resulted in high

trimming losses, higher cooking losses and increased headspace within the non-flexible packaging containers, which affected the dose distribution during irradiation. To eliminate these problems and to produce a higher quality and more economical product, research was initiated on formed meat rolls utilizing the meat from the whole cuts as well as restructured from smaller pieces.

To provide the binding mechanism necessary to form the restructured product into uniform rolls, sodium chloride and food-grade phosphates (sodium tripolyphosphate (TPP)) were added to the beef rolls. Action by the Consumer and Marketing Service of the US Dept. of Agriculture approved the use of sodium TPP and sodium hexametaphosphate in "cooked and fresh beef and beef prepared for further cooking." (Federal Register, Vol. 35, No. 193, Oct. 3, 1970). The allowable amount of phosphates is 0.5 percent in the finished product.

The effect of the addition of condensed phosphates on fresh and cured meats has been reported by many investigators. Several theories have been advanced to explain the mechanisms by which the meat is affected by phosphates, alone or in combination with common salt, sodium chloride. Water retention, water binding, water holding capacity, cured meat volume, pH and meat swelling were studied to demonstrate the effects of the additives.

Several investigators have found a definite effect of pH on the water retention and swelling of meat samples. Water retention in meat is at a minimum at its isoelectric point, which is pH 5.3 to 5.5. Grau, et al. (1953), Ham (1960) and Wierbicki, et al. (1963) found that increasing the alkalinity of the meat resulted in an increase in water retention properties. Hamm and Grau (1955) reported that the sequestering effects of some phosphates resulted in an increase in water retention, particularly by sequestering calcium and zinc ions of a meat (Hamm, 1956). Wierbicki, et al. (1957b) reported that the addition of calcium chloride and magnesium chloride to beef increased the water retention properties when heated at 70 ^{o}C. Swift and Ellis (1956) also showed an increase in water retention could be obtained by the addition of magnesium chloride. Sherman (1961a) found that fluid retention, as affected by sodium chloride or other neutral salt solutions, depended upon the degree of ion absorption by meat proteins. The anions are absorbed preferentially and are directly related to the fluid retention. With phosphate solutions, fluid retention at 0 ^{o}C shows a significant correlation with pH. The ionic strength of the solution was important only insofar as it controlled the rate of absorption. The greater the ionic strength, the greater the absorption of ions. Mahon (1961) found that salt concentration without pH adjustment is the key to obtaining maximum water retention in cured meats.

The role of phosphates on the water retention and meat swelling has been studied by several investigators. Hellendoorn (1962) found that sodium pyrophosphate and sodium TPP had a marked and specific activity on water retention in heated meat samples at a pH range of 6.0 to 6.5, with pyrophosphate being slightly superior. TPP had the highest activity followed by tetrapoly phosphate, hextametaphosphate, pyrophosphate and orthophosphate in that order.

Sherman (1961b) found an overall reduction of fluid retention in samples of ground lean pork meat mixed with solutions of alkaline phosphates or sodium chloride when the samples were heated at various temperatures. He reported that in samples with the additive concentrations not exceeding 2% and heated in a range of 25 to 100 ^{o}C, the maximum fluid retention occurred at 50 ^{o}C, followed by an overall decrease with increasing heating temperature.

Swift and Ellis (1956) reported the importance of maintaining low temperatures in a range of 0 to +5 ^{o}C, when using alkaline phosphate additives to obtain optimum

water retention activity in raw meat samples. These results showed that 16 hours at 0°C was optimum for maximum water retention. Mahon (1961) found no effect of holding time on meat samples with higher concentrations of salts and phosphates. However, at the lower concentrations an effect of holding time was found. He also determined a synergistic effect on water retention by the addition of salt and phosphates. An increase of water retention was found when a combination of salt and phosphates was used as compared with samples containing only salt or phosphates. Shults and Wierbicki (1972) found that pyrophosphate had the greatest effect on the pH, water holding capacity and swelling of beef muscle, with TPP having a somewhat lesser effect. A concentration of 0.3% TPP was sufficient to achieve maximum effects on the water holding capacity. Higher levels did not resul in any appreciable benefits.

The development of a fresh or fresh-like irradiated meat product that can be stored unrefrigerated has long been a goal of the irradiated meats program. Enzymes responsible for the deterioration of the meat on storage were studied, to provide information for accomplishing this goal. These enzymes were identified as the proteolytic enzymes by Doty and Wachter (1955). The enzyme activity caused increases in the nonprotein nitrogenous constituents of the meat and resulted in the development of off-flavors and a degradation in its texture.

Early works showed that irradiation at sterilizing doses alone, did not inactivate all the proteolytic enzymes in meat, (Doty and Wachter, 1955). They found little reduction in the activity of proteolytic enzymes in beef muscles irradiated at 50 kGy. At a greater irradiation dose of 160 kGy there was a reduction by approximately 50 percent in the proteinase activity in the beef muscle.

Early experiments to develop a nonthermal method for inactivating proteolytic enzymes were not successful. Ultrasonic vibrations were found ineffective (Landmann, 1958). Altering the chemical structures of the meats by addition of chemicals and changing the pH were also unsuccessful. Presently, the only reliable method for inactivating enzymes is by heat.

Pearson (1959) found beef heated to a 77 °C internal temperature before irradiation, was more acceptable after three and six months storage, than beef heated to lower internal temperatures. Chiambalero, et al. (1959) determined a time-temperature relationship for the heat inactivation of proteinases in beef; he found proteolytic enzymes inactivated in beef heated to an internal temperature of 60 °C when heated for 23 minutes; 66 °C when heated for 6 minutes; 71 °C when heated for 1.5 minutes and 77 °C when heated for 17 seconds. However, Landmann (1961) reported that proteolytic activity in beef cannot be completely destroyed at 60 °C unless it is held for at least one hour. Artar (1960) also reported that beef should be heated to a 71 or 77 °C internal temperature before irradiation to avoid any significant increases in the nonprotein nitrogenous constituents in the beef. This is in agreement with the works of Cain (1955) and Drake (1957), who reported irradiated beef, precooked to 71 °C, did not undergo degradative changes during storage.

More recent investigations using C-14 labeled hemoglobin as the substrate (Roth, et al., 1971) has shown that gamma irradiation alone destroys up to 75% of the proteolytic enzymes using a dose of 40 to 60 kGy and the heat treatment (blanching)was more effective in this respect, especially when carried out at 70 °C. A combination of an irradiation dose of 45 to 52 kGy plus blanching at 65 to 70 °C destroys at least 95% of the proteolytic activity found in beef (Losty, et al., 1973).

Previous research has not conclusively determined the time and temperature

relationship for inactivating proteolytic enzymes in beef. Only one paper reports the effects of irradiation on the sensory characteristics of beef precooked at different temperatures and time intervals. Artar (1961) found that beef cooked to 77 °C before irradiation had less irradiation flavor and was more acceptable than beef precooked to lower internal temperatures.

The data available on the inactivation of enzymes in beef indicate a possibility of lowering the temperature required to inhibit the activity of the proteolytic enzymes. If this is so, the production of a fresh-like meat product can be achieved, since 60 °C is below the temperature for denaturing the meat pigment protein, myoglobin. Shults, et al. (1975) studied the effects of gamma radiation on proteolytic enzymes (proteases) in fresh beef, pork and chicken muscles using a rapid method for analysis which utilized a bovine hemoglobin substrate labeled with radioactive $K^{14}CNO$ as the substrate. The enzyme preparation was incubated with the C^{14} labeled substrate for 24 hours at 37 °C. The amount of radioactivity recovered in the trichloroacetic acid (TCA) soluble fraction after precipitation of the protein was used to measure the quantity of residual proteases. The sensitivity of the analyses was greatly improved by the substitution of 1,4-dioxane in place of toluene as the diluent in the liquid scintillation counting solution used to analyze the radioactivity in the acid supernatant liquid of the precipitated proteins.

Samples of raw beef, pork and chicken muscles were gamma-irradiated at doses of 20, 40, 60 and 80 kGy and at irradiation temperatures of +21, 0, -30 and -80 °C. The results showed a significant effect of both irradiation dose and temperature on the proteases. Irradiation with 20 kGy at -80 °C resulted in no reduction of proteolytic enzymes in beef, a 13% reduction in chicken and a 30% reduction in pork. Irradiation with 80 kGy at 21 °C resulted in an 86 to 91% reduction of proteolytic enzymes in three muscles.

Cohen, et al (1999) conducted a series of experiments to determine the effect of different variables on the quality of an irradiated ground beef product. Factors studied include: different food grade phosphate, NaCl content, fat content and size of grind. The influence of these variables on the percent cooking loss (moisture retention), Kramer shear press values and organoleptic scores were studied. The addition of phosphates and NaCl was desirable in controlling cooking losses. The most effective phosphate was tetrasodium phosphate. The addition of NaCl decreased the shear force required to penetrate the beef patty, i.e. it tenderized the product. Phosphate addition did not affect the shear press force. Irradiation with sterilizing doses had a marked effect on decreasing the shear press force.

Experiments were also conducted to determine the effects of textured soy proteins (TSP), soy protein hydrolysates and fat levels on the texture, cooking losses, meat swelling and sensory characteristics of irradiated ground beef patties, (Cohen, et al., 1976). The addition of TSP incurred increased cooking losses and also increased the shear press force. No significant differences were found between TPP addition and pyrophosphate addition on the quality of the beef patties. An acceptable irradiated ground beef patty was prepared using 20% TSP, 1.0 NaCl and 0.5% phosphate.

Research on radappertized cured meats has been concentrated mainly on ham products. The technological parameters for production of highly acceptable, shelf-stable irradiated ham has been reported by Wierbicki and Heiligman (1973), Wierbicki, et al. (1974) and Wierbicki, et al. (1975). Investigations of other cured meats have received little attention.

Regulations by the USDA (1975) eliminating the use of sodium nitrate as a curing ingredient in all cured meats, except dry cure and fermented sausage, made it

necessary to investigate the curing additives and processing parameters for producing irradiated corned beef.

Many investigators have reported the effects of irradiation dose and temperature on the sensory, chemical and microbiological properties of noncured beef, pork and chicken. (Coleby, et al., 1961; Kauffman, et al., 1969; Snyder, 1960; Wadsworth and Shults, 1967 and Shults and Wierbicki, 1974. Shults, et al. (1975) also reported the irradiation effects of dose and temperature on cured ham. All the investigators found that low temperatures reduced the deleterious effects of irradiation which resulted in improved quality of the products. The irradiation dose was found to significantly affect the quality of the meat products (Shults, et al., 1974, 1975). The higher doses resulted in more radiation induced changes which lowered the product quality. Grecz, et al. (1971) found that as the temperature during irradiation was lowered, the resistance of C. botulinum spores increased. Annelis, et al. (1972) determined that the lethal 12-D sterilizing dose for corned beef irradiated at -30 $\pm$10 ^{o}C was 25 kGy. This 12-D irradiation dose was determined using corned beef briskets cured with 600 ppm $NaNO_3$ and 150 ppm $NaNO_2$.

Extensive investigations on irradiated cured ham have shown that the USDA allowable level of $NaNO_2$ (156 ppm) can be reduced to 25 ppm when used in combination with a minimum of 100 ppm $NaNO_3$ (Wierbicki and Heiligman, 1973). Without the small amount of $NaNO_3$ present, fading of the cured meat color occurred and preference scores were lowered.

Shults, et al. (1976) reported research conducted on radappertized corned beef briskets prepared using various levels of $NaNO_3$ (0, 150 and 600 ppm) and $NaNO_2$ (0, 25 and 150 ppm) and irradiation processed at three dose levels (25, 35 and 45 kGy) and three irradiation temperatures (0, -30 and -80 ^{o}C) using a gamma Co^{60} source. Sensory characteristic and preference ratings were determined by expert technological panels and by measurements of reflectance with a Tristimulus Reflectometer™. Samples were tested with and without the addition of water soluble spice. Increasing the irradiation dose and temperature resulted in a decrease in the ratings for the sensory characteristics and for preference. Significant differences were found in the ratings for the sensory characteristics and preference of samples with the high vs. low additions of $NaNO_2$ and $NaNO_3$. Addition of water soluble spices did not increase the acceptability of the samples. Differences in color intensity were found in samples prepared with additions of $NaNO_2$ and $NaNO_3$. Color intensities decreased when only $NaNO_3$ (without $NaNO_2$) was used and with the 25 ppm addition of $NaNO_2$. Color ratings were significantly affected by the irradiation dose and temperature.

Shults, et al. (1999) described the effect of radiation processing on the quality of beef loin steaks and restructured beef. Changes in sensory properties, shear press values and hydroxyproline content were measured. There were changes in texture due to both irradiation dose and temperature. However, all the irradiated steaks tested in the acceptable range.

PRODUCTS AND METHODS

A. Effects of Irradiation Temperatures

a. Beef Loins

Materials

Boneless beef loins, the Longissimus muscle, of both US Choice and Commercial grades were used in an experiment designed to show the effects of irradiation on the sensory characteristics of high and low quality beef products.

Methods

The products were enzyme inactivated at 104 ^{o}C in a steam retort to an internal temperature of 73 to 76 ^{o}C. Immediately after the desired internal temperature was reached, the products were packed in 404 x 700 or 404 x 200 cans, lined with a "C" oleoresinous enamel. The temperature of the product at closing was 43 to 49 ^{o}C. The cans were hermetically sealed under a pressure of 7 $\pm$ 1 kPa, frozen at -40 ^{o}C and held until irradiation.

All the samples, except those designated as controls, were irradiated in a Co^{60} source and received a total dose of 45 to 56 kGy. It is noted that the experimentally determined 12-D sterilizing doses, using the Schmitt and Nank Method, are 47 kGy at -30 ^{o}C and 57 kGy at -80 ^{o}C irradiation temperature. However, for standardizing research results obtained prior to determining these sterilizing doses, a dose of 45 to 56 kGy was used for all temperatures of irradiation. The desired temperatures of irradiation were obtained by placing the cans in an insulated container during irradiation and controlling the lower temperatures with nitrogen in a vapor or liquid state. The exact temperatures of the product during irradiation were recorded by thermocouples inserted in the cans. The temperatures were controlled during irradiation to $\pm$ 10 ^{o}C of the desired temperature, except for -185 ^{o}C which was controlled within the ranges of -180 to -196 ^{o}C.

Evaluation

The samples after standardized cooking were evaluated by a panel of trained technologists (six to eight panelists per test) for the sensory characteristics: off-odor, irradiation flavor, texture, i.e. friability, mushiness, discoloration and off-flavors other than irradiation flavor. An intensity scale of one to nine (one denoting "none" and nine denoting "extreme") was employed in evaluating the sensory characteristics.

Preference ratings were obtained using consumer type panels of 36 untrained panelists and technological panels of six to eight trained panelists. For this kind of organoleptic evaluation the hedonic scale of 1 to 9 was used, with one denoting "dislike extremely" and nine "like extremely" and 5 a neutral "neither like nor dislike".

The irradiated samples were stored at 21 to 26 ^{o}C for one year. Evaluations were made at one week and three, six, nine and twelve months, except where otherwise stated. Technological panel tests were performed at each withdrawal and consumer panel tests were performed after one and three months storage.

Data Analysis

The data for the sensory characteristics and preference ratings of each sample were pooled and statistically analyzed. The results of the technological and consumer

panels were analyzed separately. Significant differences between samples, in respect to sensory characteristics and preference ratings were computed using an analysis of variance table and the multiple range test (Steel and Torrie, 1960). Significance was determined at the 95% confidence level in all cases.

Results and Discussion

The results of the sensory evaluation of the irradiated beef loin over a wide range of temperatures are shown in Table 1. It is evident that the intensities of irradiation flavor, mushiness and friability were decreased substantially as the irradiation temperature was lowered. However, little reduction of the intensity ratings in the loins resulted by lowering the temperature below -80 °C. The samples irradiated in the nonfrozen state, which had intensities in the moderate range, were judged to be unacceptable for testing after 3 months of storage. The degradation of the textural characteristics was the primary factor making these samples unacceptable.

Table 1- Effects of Irradiation Temperatures on Flavor and Textural Characteristics of Commercial Beef Loins

Temp. °C	Irradiation Flavor	Mushiness	Friability
+60	4.1	5.3	5.0
+21	3.3	3.4	3.0
-40	2.9	2.5	1.9
-80	2.1	2.0	1.8
-185	1.5	2.0	1.9

16 member panel, either 1 month of frozen or 3 months of unfrozen storage
Irradiation dose: 45 to 56 kGy

The results shown in Table 2 were obtained from another set of samples of beef loin that had been irradiated in a range of 0 to -185 °C. The largest differences in the intensity ratings were found in samples irradiated at 0 and -40 °C. After both 3 and 10 weeks of storage, the intensities for irradiation flavor in the 0°C samples were found to be significantly different from the other irradiated samples. The ratings for the textural characteristics and technological preference were not significantly different due to the small number of panelists on each of the tests. The consumer ratings for preference found the 0 °C sample significantly different from the other samples.

Table 2 - Effects of Irradiation Temperature on the Sensory and Preference Ratings of Commercial Beef Loins

Irradiation Temp.,°C	Storage Time of Months									
	Irradiation Flavor		Mushiness		Friability		Preference Technical		Preference Consumer	
	0	3	0	3	0	3	0	3	0	3
0	3.9*	4.4*	2.8	2.4	4.2	3.0	4.7	5.6	4.8*	4.8*
-40	2.6	1.9	1.8	1.4	3.4	3.0	5.9	6.1	5.7	5.8
-120	2.3	1.4	1.8	1.6	2.8	2.3	6.0	6.3	5.7	6.1
-185	2.4	1.6	1.4	1.5	1.6	2.8	5.8	6.1	5.9	5.7

* significantly different from other samples at 0.05 level

8 member technological panel 36 member consumer panel
Irradiation dose: 45 -to 56 kGy

b. Beef Loin and Round Muscles of Different Quality Grades

Materials

The beef muscles utilized for these studies were from boneless loins and rounds of US Choice and Commercial grades of beef

Methods

To investigate the effects of irradiation on the sensory characteristics and preference ratings of various cuts of beef, loins (Longissimus muscle) and the top round (Semimbranosus muscle) were irradiated at 0, -80 and -185 °C.

Three sections of beef round were used to determine any difference in the effects of irradiation on the different muscles. The three muscle sections of the U.S. Choice round were the top, Semimembranosus, bottom, Biceps Femoris and Semitendenosus and the knuckle consisting of the Rectus femoris, Vastus intermedius, Vastus lateralis and the Vastus mediole.

Results and Discussion

US Choice and Commercial grade beef loins (Longissimus) and US Choice grade top round (Semimembranosus) packaged in cans after thermal enzyme inactivation were irradiated at a dose of 45 to 56 kGy, at temperatures of 0, -80 and -185 °C. Differences in sensory characteristics and preference ratings were determined on cooked irradiated beef by technological panels after zero, one and two months of storage.

Table 3 shows the results of the evaluations on US Choice beef loins. There were no significant differences in the sensory characteristics and preference ratings between -80 and -185 °C irradiated samples and the control for all the sensory characteristics except the irradiation flavor, off-odor and preference at 3 months. The nonirradiated frozen control sample was significantly preferred to all the irradiated samples.

US Choice Beef Loins

Irrad. Temp. °C	Storage Time days	Sensory Characteristics: Dis-color	Off Odor	Irrad. Flavor	Off Flavor	Mushi-ness	Fria-bility	Pref-erence
0	0	3.9	4.9	5.4	1.3	3.5	3.3	3.0
0	30	4.3*	2.9*	4.5*	1.3	3.5*	3.6*	4.9*
0	60	3.0	3.3	3.8	1.7	3.3	4.3	4.1
-80	0	2.0	3.6	3.6	1.3	2.9	2.6	5.1
-80	30	2.3	2.3**	2.8**	1.1	2.0	2.0	5.8**
-80	60	1.8	2.1	2.1	1.7	2.8	3.1	5.9
-185	0	3.9	2.8	3.4	1.6	2.4	2.9	5.0
-185	30	2.6	2.4**	3.0**	1.4	2.3	2.3	5.8**
-185	60	1.9	2.0	2.5	1.6	2.3	2.5	6.2
NA	0	1.4	1.3	1.1	1.1	1.5	1.8	7.5
Frozen	30	1.1	1.1	1.0	1.0	1.5	1.4	7.5
Control	60	1.3	1.1	1.0	1.3	1.4	1.5	7.3

* 0 °C samples rated significantly different from the -80, -185 °C and nonirradiated samples for preference and all sensory characteristics except off-flavor (0.05 level)

** Significantly different from control (0.05 level)

8 member panel irradiation dose - 45 to 56 kGy

Evaluation of the results obtained by the technological panel on US Choice top round beef irradiated at 0, -80 and -185 °C (Table 4) shows the -185 °C irradiated sample being similar to the control. Small, but significant, differences were found between the -80 °C sample and the nonirradiated control, for intensity ratings of discoloration, friability and irradiation flavor at 30 days of storage. No significant differences were found between the -80 and -185 °C samples. The 0 °C irradiated samples were scored as unacceptable by the panelists. This was probably due to the induced undesirable changes in the sensory characteristics.

Table 4 - Effect of Irradiation Temperature on the Quality of US Choice Top Rounds of Beef

Irrad. Temp. °C	Storage Time days	Sensory Characteristics: Dis-color	Off Odor	Irrrad. Flavor	Off Flavor	Mushi-ness	Fria bility	Pref-erence
0	0	3.4	3.5	3.9	1.1	2.9	2.4	4.4
0	30	4.4*	3.4*	4.5*	1.3	2.5	3.5***	3.3*
0	60	4.0	2.8	2.9	2.4	3.7	4.4	4.8
-80	0	1.8	1.4	1.9	1.3	1.4	2.3	6.4
-80	30	2.9**	2.4	2.4**	1.0	2.6	2.8**	5.2**
-80	60	2.3	1.9	2.0	2.0	2.1	3.1	5.6
-185	0	1.9	1.4	1.8	1.1	1.6	1.9	6.4
-185	30	2.8	1.5	1.3	1.1	1.6	1.6	6.5
-185	60	2.5	1.8	1.8	2.0	1.9	2.6	5.6
Non-irrad. Frozen Control	0	1.0	1.1	1.0	1.0	1.0	1.0	7.9
	30	1.3	1.3	1.0	1.1	1.9	1.8	7.3
	60	2.4	1.3	1.3	1.6	1.4	1.6	6.6

* Significantly different from the -80, -185 °C and control samples (0.05 level)

** Significantly different from the control sample (0.05 level)

*** Significantly different from the -185 °C and control samples (0.05 level)

8 member panel Irradiation dose: 45 to 56 kGy

The results from the technological panel scores on the three types of materials listed in Tables 3 and 4 indicated the necessity of irradiation at cryogenic temperatures. Irradiation at -80 °C yielded acceptable products and only a minor decrease in product quality when compared to the control . A higher quality was obtained by further reducing the irradiation temperature to -185 °C.

For additional studies on the irradiation of different cuts of beef, top round, bottom round and the knuckle sections, US Choice rounds of beef were irradiated at -80 °C. The samples were stored for one year at 21 °C and evaluated after zero, one, three, six and twelve months of storage. The results from these tests are shown in Table 5.

The intensity ratings for the sensory characteristics were in the range of one (none) to three (slightly). This indicates that three sections of the beef round were only slightly affected by irradiation processing. Preference ratings showed that all irradiated samples were acceptable after one year of storage at 21 °C. However, the non-irradiated control was significantly preferred.

Table 5 - Effect of Irradiation on the Quality of Three Sections of Beef Rounds

Sample	Storage Time Months	Sensory Characteristics: Dis-color	Off Odor	Irrad. Flavor	Off Flavor	Mushiness	Preference
Top Round	0	1.5	2.5	2.5	2.6	1.3	5.5
	3	2.1*	1.8	1.9	2.8*	2.5*	6.0
	6	1.7	1.9	1.7	1.9	2.1	6.4
	12	2.0	2.1	2.9	1.3	2.4	5.4
Bottom Round	0	1.5	1.7	1.7	2.2	1.3	6.7
	3	1.6	1.6	1.8	2.3	2.0**	6.0
	6	1.4	1.6	1.7	1.8	1.3	6.9
	12	2.1	2.1	2.6	1.7	2.1	6.6
Knuckle of Round	0	1.2	2.7	1.8	2.3	1.7	6.7
	3	1.8	1.8	2.1	2.1	2.6	6.2
	6	1.6	1.9	1.7	1.8	2.0	6.5
	12	1.7	2.4	2.9	1.3	2.7	5.9
Top Round Control	0	1.5	1.3	1.0	1.8	1.2	7.9
	3	1.5	1.1***	1.1***	1.6	1.9	7.0***
	6	1.2	1.0	1.0	1.3	1.6	7.4
	12	1.0	1.0	1.0	1.1	1.0	7.4

* Significantly different from nonirradiated control (0.05 level)
** Significantly different from knuckle section (0.05 level)
*** Significantly different from all irradiated samples (0.05 level)

iIradiation dose: 45 to 56 kGy at -80 °C 8 panelists per test

The results shown for the irradiation effects on different cuts and grades of beef indicated that the beef rounds of both grades and the lower graded beef (US Commercial) loins were acceptable for use as irradiated beef items. Additionally, an irradiation temperature of -80 °C was sufficient to produce acceptable products. However, as mentioned in the introduction, it has been determined that, as the temperature of irradiation is lowered, the dose must be increased to assure 12-D sterility in the product (Grecz, et al. 1965, 1971).

To compare the effects of different doses on the beef, US Choice top rounds were irradiated at minimum dose of 30, 45 and 60 kGy at the lowest temperature, -185°C. The results in Table 6 show that, as the dose increases, the preference rating of the samples decrease. The sample irradiated at 30 kGy was significantly preferred to the 60 kGy sample. The intensity ratings for discoloration, off-odor and irradiation flavor also increased with increasing dose.

Table 7 gives the results on US Choice top round roast irradiated at the two 12-D irradiation sterilizing doses: 47 kGy at -30 °C and 57 kGy at -80 °C. Preference data from four tests over a 90 day storage period at room temperature show that roast beef irradiated at these conditions was in the low acceptance range. However, no significant differences were found between the two irradiated beef samples, but the roast beef irradiated with 47 kGy at -30 °C tended to rate higher in preference than the roast beef irradiated with 57 kGy at -80 °C.

Table 6 - Effect of Different Irradiation Doses on the Quality of Irradiated US Choice Beef Roast

Irradiation Dose kGy (min)	Sensory Characteristics				
	Discoloration	Off-Odor	Irradiation Flavor	Mushiness	Preference
0	1.2*	1.0*	1.8*	1.2	7.6*
30	1.9	2.1	2.6	2.1	6.4**
45	1.9	2.2	3.2	2.4	6.2
60	2.1	2.4	3.4	2.4	5.5

* Significantly different from the other samples (0.05 level)
** Significantly different from 60 kGy sample (0.05 level)

8 panelists per test Irradiated at -185 °C

Table 7 - Effect of the 12D Sterilizing Dose at Different Temperatures on the Quality of US Choice Beef Roasts

Irrad. Dose kGy	Irrad. Temp. °C	Storage Time Days	Sensory Characteristics						
			Dis-Color	Off Odor	Irrad. Flavor	Off Flavor	Mushiness	Friability	Preference
47	-30	0	2.1	1.4	2.1	2.0	2.1	3.3	5.7
47	-30	30	2.7	2.3	2.7	1.7	1.4	2.3*	5.7
47	-30	60	2.3	2.6	2.6	2.0	2.9	3.3	5.1
47	-30	90	3.3	3.9	3.1	2.4	1.3	3.4	4.5
57	-80	0	1.7	1.9	2.3	1.4	1.9	3.0	5.6
57	-80	30	2.4	2.9	3.4	2.3	2.9	2.9	5.0
57	-80	60	2.0	2.1	2.1	2.0	2.0	2.6	5.0
57	-80	90	2.4	2.6	3.1	2.4	1.3	2.4	4.9
nonirradiated		0	1.4	1.3	1.1	1.3	1.0	1.5	7.3
frozen		30	1.7	1.7	1.1**	1.9	1.0	1.9	7.3
control		60	1.3	1.0	1.0	1.3	1.3	1.7	7.1**
		90	1.9	1.3	1.3	1.7	1.0	1.3	6.3

* Significantly different from the non-irradiated sample (0.05 level)
** Significantly different from all the irradiated samples (0.05 level)

Samples stored at room temperature

Results from the studies given in Tables 6 and 7 emphasize the problems encountered by technologists in achieving a product of high acceptance when the microbiological sterility requirements are considered. By lowering the irradiation temperature, a corresponding increase in the irradiation dose must be made to assure sterility. As the data indicate, when the dose increases the deleterious effects of irradiation increase and a lowering of product quality results. Data in Table 8 show that the sterilizing doses of 47 and 57 kGy at -30 and -80 °C respectively, produce roast beef products of similar quality. The cost of irradiation with a dose of 57 kGy at -80 °C are greater than irradiation with a dose of 47 kGy at -30 °C. A liquid nitrogen

irradiation system would be required for production of beef irradiated at - 80 °C, whereas, at least for freezing the product prior to irradiation, mechanical freezers could be utilized for irradiation at -30°C. Thus, the most favorable balance of product quality, irradiation cost and required sterilizing dose appears to be a dose of 47 kGy at an irradiation temperature of about -30 ± 10 °C. Consequently, this irradiation temperature was used at Natick for developing radappertized beef and other food products.

B. Time-Temperature Relationships for Inactivation of Meat Enzymes

a. Loin Steaks

Materials and Methods

US Choice Beef Loins, the longissimus muscle were sliced into 13 mm steaks weighing 110 to 120 g. The steaks were packaged in flexible, foil-laminate pouches and immersed into a controlled temperature water bath. Fifteen to seventeen minutes were required before the internal temperature of the steaks were within 1 to 2 °C of the temperature of the water bath. The steaks were cooked at the following temperatures and held for the specified time intervals after the desired internal temperature were reached as shown in Table 8.

Table 8 - Experimental Conditions

Temp. °C	Time minutes
Experiment 1	
55	30, 60, 120, 360
60	30, 60, 120, 180
66	10, 30, 60
71	1, 10, 30
77	1
Experiment 2	
60	180, 240, 300, 360
66	10, 30, 30, 60
71	5, 10, 15
77	1

After cooking at each specific time interval, the pouches were immersed in an ice water bath for rapid cooling. The steaks were removed from the pouches and hermetically sealed at 16.6 kPa of pressure in metal containers. The samples were irradiated to a dose of 45 to 56 kGy at a controlled temperature of -180 ± 10 °C. This cryogenic temperature was utilized in an attempt to minimize irradiation effects.

Chemical Analysis

The samples were chemically analyzed in accordance with standard AOAC (1970) procedures to determine the changes in the nonprotein nitrogenous constituents. The percent of nonprotein nitrogen [(NPN/N) x 100] was used as a guide to determine the amount of protein degradation in the product during storage.

Results and Discussion

The irradiated US Choice loin steaks, cooked as outlined in Tale 8, were stored at 21 °C and evaluated after one week and three months of storage by technological panels. Intensity ratings for the characteristics of mushiness and off-flavor for all samples ranged from (trace) to 3 (slight) after one week of storage. At three months of storage, samples pre-cooked at 55 °C were deteriorated to the extent that they were not suitable for sensory testing. The intensity ratings for mushiness and off-flavor of the samples irradiated at 60 °C increased to range of 4 (below moderate) to 5 (moderate). Whereas the irradiated samples pre-cooked at 66 and 71 °C showed no increase in the intensity ratings of off-flavor during 3 months of storage, they did show an increase in the intensity ratings for mushiness.

Table 9 - Effect of Blanching Temperature and Time on Mushiness and Off-Flavors of Beef Steak

Cooking		Intensity Ratings				Hedonic	
Temp.	Time	Mushiness		Off-Flavor		Preference	
°C	Min.	Storage Time, Weeks					
°C	min.	1	13	1	13	1	13
55	30	2.0	*	2.2	*	6.1	*
55	60	1.8	*	2.1	*	6.5	*
55	120	2.8	*	2.4	*	6.0	*
55	360	2.4	*	2.4	*	6.4	*
60	30	2.8	4.0	2.0	3.8	6.5	3.6
60	60	2.0	4.4	2.5	4.6	6.5	3.9
60	120	3.7	4.2	3.0	3.8	5.7	4.4
60	180	3.0	4.4	2.8	4.4	6.0	3.5
66	10	2.8	3.6	2.1	2.6	6 .7	5.0
66	30	2.1	3.6	2.9	2.2	6.7	5.0
66	60	2.1	3.0	2.4	2.2	6.4	5.4
71	1	1.9	3.9	2.4	2.1	6.3	4.9
71	10	1.8	3.9	2.5	1.9	6.8	4.9
71	30	2.7	3.5	2.5	1.8	6.4	5.5

* Samples too deteriorated for testing
8 Panelists per test

Preference ratings of all the samples were in the acceptable range after one week of storage. After three months of storage, the 60 °C precooked irradiated samples were rated unacceptable. Evaluation of the data indicated that the steaks must be pre-cooked 66 °C or above to reduce off-flavor formation and the degradation of texture on storage. Cooking at 55 °C for 360 minutes or 60 °C for 180 minutes was not sufficient . Increases in the mushiness and off-flavor intensities were detected which resulted in unacceptable product.

The chemical analysis for total nitrogen (N) and NPN were performed after one year of storage at 21 °C. Table 10 shows that the NPN values increased after three months of storage; storage up to one year resulted in only small additional increases

of NPN except for the irradiated samples cooked at 55 °C for 30 minutes.

Table 10 - Changes in Non Protein Nitrogen Content of Irradiated Beef Steaks

Temp.	Time	Storage Time, Months											
		0			3			6			12		
°C	min.	N*	NPN*	% NPN	N*	NPN*	% NPN	N*	NPN*	% NPN	N*	NPN*	%NPN
55	30	2.90	0.28	9.6	3.42	0.58	16.9	3.33	0.62	18.7	3.09	0.76	24.9
55	60	2.88	0.28	9.7	3.02	0.50	16.6	2.78	0.48	17.3	3.58	0.70	19.5
55	120	3.05	0.30	9.9	3.46	0.57	16.5	3.44	0.62	18.0	3.12	0.55	17.6
55	360	2.91	0.27	9.3	3.59	0.48	13.4	3.13	0.48	15.3	3.32	0.53	15.9
60	30	3.45	0.34	9.9	3.59	0.57	13.9	3.20	0.52	16.2	3.54	0.62	17.5
60	60	3.12	0.32	10.3	3.30	0.46	14.4	3.32	0.64	15.7	3.36	0.56	16.7
60	120	3.19	0.32	10.0	3.68	0.53	15.4	3.43	0.66	19.2	3.62	0.58	16.0
60	180	3.62	0.38	10.5	3.44	0.47	13.7	3.32	0.50	15.0	3.11	0.50	16.1
66	10	3.66	0.35	9.6	3.48	0.43	12.4	3.54	0.46	13.0	3.24	0.42	12.9
66	30	3.31	0.28	7.9	3.25	0.32	9.8	3.46	0.36	10.4	3.21	0.30	9.3
66	60	2.97	0.26	8.6	3.53	0.35	9.9	3.17	0.31	9.8	3.63	0.31	8.5
71	1	3.34	0.32	9.6	3.67	0.33	9.0	3.47	0.34	9.8	3.39	0.23	6.8
71	10	3.53	0.28	7.9	3.66	0.36	9.8	3.80	0.32	8.4	4.35	0.33	7.6
71	30	4.11	0.34	8.3	4.00	0.37	9.0	4.12	0.32	7.8	3.82	0.25	6.5
77**	1	3.75	0.28	7.9	4.10	0.31	7.6	3.90	0.31	8.0	3.55	0.24	6.8

* g/100 g

** Non-irradiated control (all samples stored at 21 °C)

The results show that a cooking temperature of 66 °C for 60 minutes or 71 °C for one minute is necessary to inhibit the increase of NPN due to residual proteolysis in beef during storage. At 66 °C for 30 minutes, increased NPN values were found, but not as high as those of the other irradiated samples.

Sensory data and preference ratings for steaks pre-cooked for 5, 10 and 15 minutes are shown in Table 11. No significant differences were found among the sensory characteristics for all samples. Mushiness and off-flavor scores were in the range of 1 (none) to 2 (trace) indicating that enzymatic activity was not detected. Preference ratings were in the acceptable range and no significant differences were found.

Table 11 - Effect of Cooking Temperature and Time on the Sensory Characteristics of Irradiated Beef Steaks

Cooking		Intensity Ratings						
Temp.	Time	Dis-	Off-	Mushi-	Irrad.	Dry-	Off-	Hedonic
°C	min.	color	Odor	ness	Flavor	ness	Flavor	Preference
71	5	1.5	1.9	2.1	1.9	2.3	2.1	5.7
71	10	1.7	1.9	1.8	2.1	2.3	1.7	5.8
71	15	1.7	1.9	1.8	1.9	2.7	1.8	5.9

22 member panel No significant difference

The chemical analysis for the irradiated steaks stored at 21 and 38 °C are shown in

Table 12. The irradiated samples, pre-cooked at 71 and 77 °C, and 66 °C for 20, 30 and 60 minutes, and 60 °C for 300 and 360 minutes showed no increase in non-protein-nitrogen (NPN) after six months of storage at 21 °C. The NPN values for samples cooked at 60 °C for 180 and 240 minutes, and 66 °C for 10 minutes increased only slightly between three and six months of storage. Atfter a 20 minutes coook at 66°C it decreased between 3 and 6 months. The increases in NPN values een after three months of storage for the beef steaks cooked at 60 and 66 °C indicates that enzymes are not destroyed by the heat treatments and the enzymatic breakdown of the nitrogenous components of the
meat is responsible for this increase in NPN.

Table 12 - Effect of Non Protein Nitrogen, Time and Temperature on Irradiated Beef Steaks

Cooking		Storage Time, Months								
Temp.	Time	0			3			6		
°C	min.	N	NPN	% NPN	N	NPN	% NPN	N	NPN	% NPN
A. 21 °C Storage										
60	180	4.09	0.36	8.8	4.20	0.39	9.5	4.39	0.43	10.0
60	240	4.10	0.35	8.5	4.37	0.40	9.2	4.27	0.46	10.8
60	300	3.99	0.33	8.3	4.12	0.40	9.7	4.08	0.29	7.1
60	360	4.09	0.34	8.3	4.09	0.39	9.5	4.36	0.41	9.4
66	10	3.65	0.34	9.3	4.21	0.50	11.9	4.37	0.53	12.1
66	20	4.02	0.35	8.7	4.19	0.45	10.9	4.41	0.45	10.2
66	30	4.16	0.33	7.9	4.15	0.38	8.2	4.19	0.34	8.1
66	60	4.07	0.35	8.5	4.18	0.38	9.1	4.24	0.35	8.2
71	5	4.22	0.33	7.8	4.33	0.35	8.1	4.45	0.30	6.7
71	10	4.28	0.32	7.5	4.33	0.39	9.0	3.94	0.26	6.6
71	15	4.27	0.29	6.9	4.41	0.36	8.2	4.565	0.36	7.9
77	1	4.92	0.33	8.3	4.44	0.44	9.9	4.55	0.35	7.7
77*	1	4.12	0.30	7.3	4.55	0.36	7.9	4.80	0.31	7.1
B. 38 °C Storage										
60	180	4.17	0.46	11.0	4.14	0.57	13.8	4.36	0.52	12.9
60	240	3.98	0.41	10.3	4.35	0.54	12.4	3.46	0.49	14.2
60	300	4.16	0.44	10.6	4.23	0.55	13.0	4.03	0.51	12.7
60	360	4.06	0.42	10.3	4.19	0.50	11.9	4.15	0.55	13.3
66	10	3.27	0.40	12.2	3.95	0.60	15.2	4.07	0.70	17.2
66	20	3.99	0.42	10.5	4.26	0.54	12.7	4.04	0.58	14.4
66	30	4.18	0.38	9.1	4.16	0.46	11.1	4.40	0.51	11.6
66	60	3.88	0.36	9.3	4.51	0.47	10.4	4.50	0.51	11.3
77	5	4.09	0.36	8.8	4.38	0.38	8.7	4.17	0.38	9.1
77	10	4.16	0.30	7.2	4.51	0.38	8.4	3.79	0.29	7.7
77	15	4.36	0.32	7.3	4.12	0.34	8.3	3.80	0.30	7.8
77	1	4.50	0.33	7.3	4.45	0.35	7.9	4.50	0.36	8.0
77*.	1	4.12	0.30	7.3	4.83	0.43	8.9	4.87	0.38	7.8

* nonirradiated control ** stored at -29 °C before analysis

These results on the time-temperature relationship of the heat inactivation of enzymes indicated that, for storage up to six months at room temperature, a heat treatment of 60 °C for 300 minutes, 66 °C for 30 minutes or 71 °C five minutes is

necessary for the inhibition of the proteolytic enzymes. However, these treatments may not be sufficient to destroy all the enzymes in beef as indicated by the results from the 38 °C storage. Only samples heated to 71 °C for 10 and 15 minutes and 77 °C for one minute did not show any increase in NPN values at 38 °C storage. Losty, et al. (1973) using a C^{14} hemoglobin substrate analysis reported that a combination of heat (60 to 70 °C) and irradiation (45 to 57 kGy) may be expected to destroy at least 95% of the proteolytic activity in beef.

b. Ground Beef

Materials and Methods

The beef used for this study was fresh, chilled, seven days post-mortem, US Commercial top round (semimembranosus muscle), with a fat level of 5 to 7%. The meat was ground through a 5 mm grinding plate and uniformly mixed in a refrigerated cold room at +2 °C. The liver used was frozen calf liver.

Substrate Preparation

Four hundred mg of Bovine hemoglobin (Sigma Chemical Co., type 1, semi-purified) were dissolved in 15 cc of distilled water and adjusted to pH 6.1 with 0.1 N NaCl. The volume was increased to 20 cc with distilled water and 0.4 cc (0.04 mcurie) of $K^{14}C$ NO was added. The hemoglobin was incubated at 50 °C for two hours and allowed to stand for 18 hours at +2 °C. After 18 hours, 2 cc (20-moles) of cysteine hydrochloride, pH adjusted to 6.1, was added and the substrates incubated at +2 °C.

Enzyme Preparation

Test samples of beef muscle were homogenized using a Pyrex™ tissue culture grinder with the grinding tube immersed in ice water. The tissue samples were buffered at pH 3.8 with cirate buffer and used immediately after preparation.

Standard Tissue

The standard enzyme assay using the labeled hemoglobin substrate is described by Roth, et al. (1970). The enzyme solution (0.7 cc) was added to test tubes containing 1.4 cc of 0.2 M acetate buffer, pH 3.7, and 1 cc of substrate containing 16 mg of hemoglobin. The sample was incubated at 38 °C in a shaker water bath. 0.85 cc aliquots were removed after 0 to 24 hours in most cases.

The aliquots of the enzyme and substrate mixture were treated with 0.2 cc of ice cold 50% trichloroacetic acid to precipitate the protein, agitated in a Vortex™ mixer, and centrifuged in a refrigerated centrifuge at 2,000 rpm for 30 minutes. The supernatant fraction was filtered through glass wool to remove any particles of substrate.

Radioactive Assay

A 0.1 cc portion of the substrate-enzyme mixture was added to 15 cc of a liquid scintillation mixture in 40 cc scintillation jars. The samples were counted in a Packard™ liquid scintillation counter for ten minutes. Each sample was counted in four replicates at 0 and 24 hours incubation at 38 °C. Substrate blanks were run for each set of experiments; results on two types of scintillation solutions were obtained. Both of the scintillation solutions contained 1,4,-bis-2,5-phenyloxazolyl-benzene, 2,5-diphenyloxazole, naphthalene and 2-ethoxyethanol. The two solutions varied only in that one contained toluene and the other 1,4-diozane. Greater sensitivity

(higher readings) are obtained using 1,4-dioxane.

Packaging and Radiation Processing

The ground meat samples were packaged in 404 x 202 size cans at 7 kPa of pressure. Irradiation processing was performed in a Co^{60} gamma source at the Radiation Laboratory, US Army, Natick R&D Command. The doses stated are the minimum dose. The ranges are the minimum dose plus 25%. Irradiation temperatures were controlled within $\pm$ 10 ^{o}C using a liquid nitrogen cooling system. The dose rate was 3.24 x 10^4 kGy/sec.

Results and Discussion

The reduction in the enzyme activity of beef muscle irradiated at four doses and four irradiation temperatures are shown in Table 13. These data demonstrate a significant effect of the irradiation dose and temperature. At a dose of 20 kGy and a temperature of -80 ^{o}C, a 49% reduction in residual enzyme activity was found. At a dose of 80 kGy and a temperature of +21 ^{o}C, the reduction was 73% and 49% at -80 ^{o}C. The data on the effect of irradiation doses indicate that, as the dose increased, the residual enzyme activity significantly decreased. Similarly, as the irradiation temperature was decreased from +21 to -80 ^{o}C, the enzymes were protected from the damaging effects of the irradiation process and the resulting reduction in enzymatic activity was minimized.

Currently, the minimum 12-D sterilizing dose for irradiated beef is 37 kGy at -30 $\pm$ 10^{o}C. The data in Table 13 show that the proteolytic enzyme activity in raw beef irradiated at this 12-D dose would be reduced by only about 45%. Consequently, these enzymes must be inactivated by other means, such as thermal treatments.

Table 13 - Effect of Irradiation Temperature and Dose on the Proteolytic Enzymes of Beef Muscle

Dose kGy	Temp. °C	Radioactivity Counts (Replications)				Mean	SD	% Reduction from 0 kGy
20	+21	2306	2326	2961	2372	2491	310	48
20	0	2847	2856	3109	3244	3014	292	37
20	-30	3317	3791	2619	4153	3470	715	28
20	-80	5095	4589	5076	4679	4859	328	*
40	+21	2347	1674	2362	2313	2174	452	55
40	0	2315	2391	229	1778	2194	199	54
40	-30	2853	2891	3059	3093	2974	212	38
40	-80	3522	3552	3168	2597	3210	373	33
60	+21	2081	1350	1368	1584	1606	434	67
60	0	2151	1675	2011	1758	1899	301	60
60	-30	3140	3331	3153	3352	3244	175	33
60	-80	3933	4046	3945	3974	3975	301	18
80	+21	1175	1313	1579	1117	1296	160	73
80	0	1534	1657	1164	1587	1485	272	69
80	-30	2187	2014	1567	1688	1864	313	61
80	-80	3012	1983	3087	1835	2479	823	49
00	NA	5466	5724	4070	3964	4806	862	
Substrate		674	929	816	615	759	142	

* 1% increase in (enzyme activity) counts per minute

Analysis of Variance

Factor	*F*	significance
Dose	58.5	0.01
Temperature	37.9	0.01
Dose x Temperature	2.2	NSD

C. Effect of NaCl and Phosphate Addition on Meat Shrinkage and Swelling

Materials

The raw material utilized for this study was the semimembranosus, longissimus and triceps brachii muscles of USDA Commercial grade beef. In one experiment the semimembranosus, longissimus and biceps femoris muscles were used. The beef was chilled (nonfrozen) three to five days post mortem, obtained from a local beef supplier. After removal of the cover fat and visible connective tissue, the beef was ground through a five mm grinding plate and thoroughly mixed prior to each test.

The additives used were sodium chloride (NaCl) and the following food grade phosphates: sodium tripolyphosphate (TPP), sodium metaphosphate (MP), sodium hexametaphosphate (HMP), tetrasodium pyrophosphate (PP), two blends of commercial phosphates and Curafos 22-4™ (a mixture of TPP and HMP). All phosphates were obtained by the courtesy of the Calgon Corp., Pittsburgh, PA. The additives were added directly to ground beef, mixed thoroughly, and held overnight in a refrigerator at +2 to 4 °C prior to evaluation.

Methods

The water holding capacity (meat shrinkage) was determined by the method of Wierbicki, et al. (1957) with the following modifications:

a. The dimensions of the tubes were 180 mm long with a top chamber 35 mm in diameter (outside) and the bottom chamber 20 mm in diameter. The bottom section of the tube was graduated in divisions of 0.1 cc from 0 to 10 cc.

b. Meat samples (with or without additives) were 20 g. Each meat sample was run twice in duplicate. Each shrink datum tabulated or presented in the figures is an average of four tube readings with a standard deviation less than 5% relative.

c. The heating times and temperatures varied, depending upon the experiment. The minimum heating time of the meat, with and without the additives, required to obtain representative shrink data was 30 minutes. Unless otherwise indicated, 30 minutes heating was used for shrink determination.

d. After heating, the samples were centrifuged at 900 G (1,000 rpm) for 15 minutes using an International Model V™ centrifuge. The amount of juices lost during heating and centrifugation was measured. This loss of juices or the meat shrinkage, is expressed as percent of the total mass of the samples.

The meat swelling (water-binding capacity) was determined by the method of Wierbicki, et al. (1962). A 50 g sample of beef, with or without additives, was blended at room temperature in a high speed blender with 150 cc of distilled water for 90 seconds. 35 g of the meat slurry were weighed in duplicate into 40 cc heavy glass centrifuge tubes. The samples were centrifuged at room temperature (21 to 25 ^{o}C) for 15 minutes at 1,000 rpm in an International Model V™ centrifuge. After centrifugation the volume (in cc) of the supernatant liquid was collected in a graduate. The percent swelling was determined by the following formula.

% Swelling: $X = 300 - (11.43 \times S)$

X = g of absorbed H_2O per g meat

S = g supernatant.

weight of slurry - 35 g; weight of meat in the slurry - 8.75 g;

weight of added water in the slurry (35 - 8.75) g;

$$\begin{aligned} \% \text{ Swelling} &= [(9.35 - 8.75) - S] \\ &= [(3 - S)/8.75]\ 100 \\ &= 300 - (100/8.75)\ S \\ &= 300 - (11.43\ S) \end{aligned}$$

All determinations were done in duplicate.

Results and Discussion

a. Effect on Meat Swelling

Data shown in Figure 1 present the effect of the phosphates on the swelling of beef. The effect is greatest for PP followed by the commercial mixture Curafos 22-4™ and TPP. The effect of MP is negligible. This is in agreement with the findings on HMP by others Bendall, 1954; Hellendoorn, 1962; Yasui, et al., 1964)

The relative effect of the phosphates on meat swelling is comparable to their relative effect on pH. This indicates that the elevation of the pH is one of the important effects of the phosphates in regard to the meat swelling. However, this effect of TPP (and the commercial blend Curafos™ containing TPP) was greater on swelling than the meat pH. This might be due to the hydrolytic effect of muscle ATP-ase on TPP, converting part of TPP to PP, which apparently has a specific

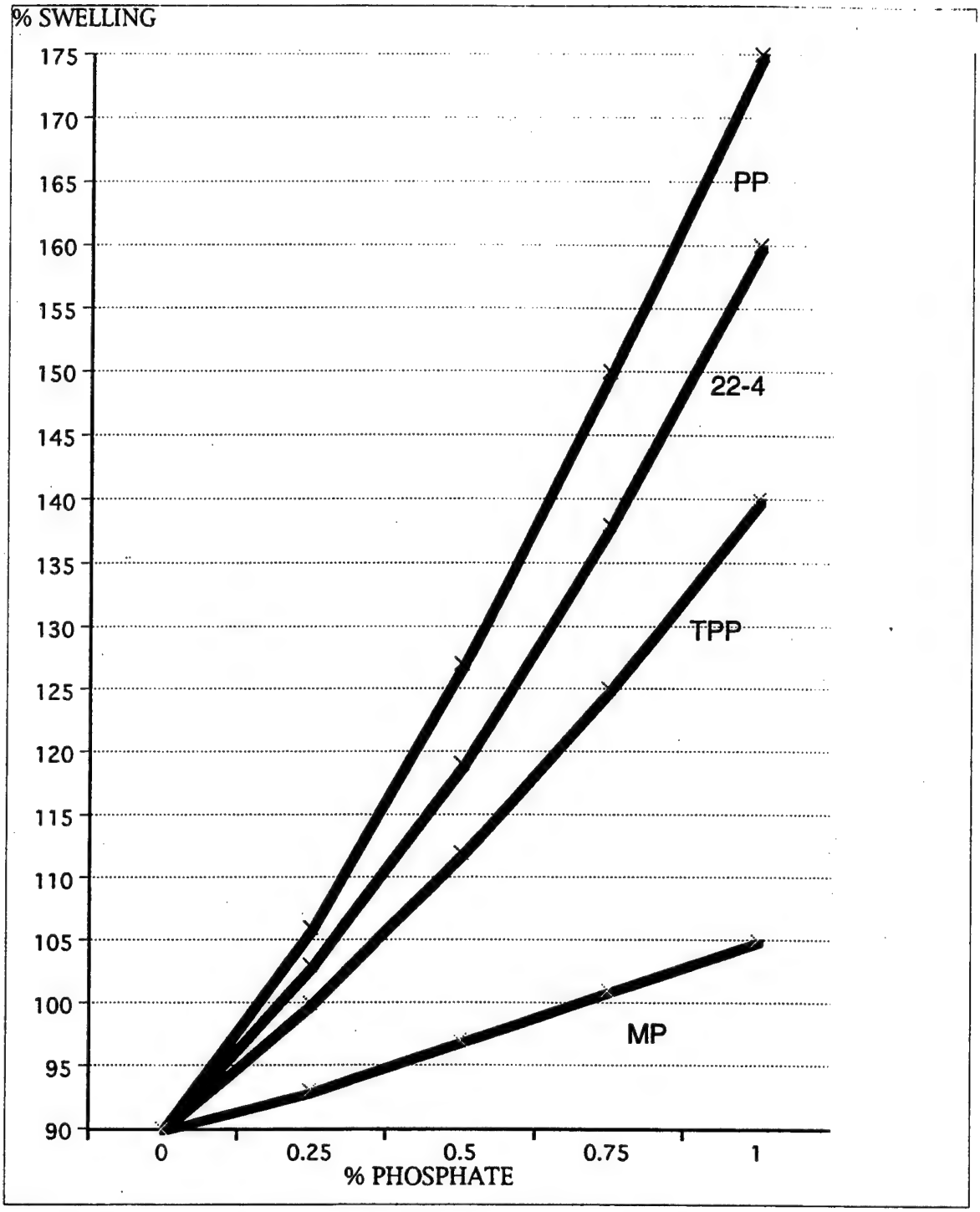

FIG. 1 - PERCENT SWELLING AS A FUNCTION OF PERCENT AND TYPE OF PHOSPHATE IN BEEF

swelling effect on lean meat in addition to its (PP) pH effect and ability to split myosin B (actomyosin) (Bendall, 1954 and Yasui, et al., 1964). Based on the swelling data, it appears that PP is probably the best phosphate for meats in which the binding of the added water is of practical importance.

To determine how condensed phosphates do affect swelling of meat in the presence of different concentrations of added NaCl, ground semimembranosus muscle of meat was blended with aqueous solutions of NaCl ranging in concentration from 0 to 10%; the ratio of meat to the solutions was one to three. The results of this investigation are shown in Figure 2. Blending of meat with 1 and 2% NaCl solutions increased the meat swelling, followed by a decrease with 3 to 5% NaCl in the solution and then by a rapid increase in the swelling with increasing the NaCl concentrations in the solutions from 5 to 10%. Addition of 0.5% TPP to the NaCl solutions increased the meat swelling, but did not change the general pattern of the changes in the meat swelling with the NaCl additions. The results can be interpreted as follows: Initial increase in the meat swelling is due to the replacement of Ca^{++} by Na^{+} on the meat proteins; the following decrease in the meat swelling is due to the exchange of Mg^{++} and K^{+} by Na^{+}; and the rapid increase in the meat swelling with increasing the NaCl concentration in the blending solutions from 5 to 10% is strictly an ionic effect of free NaCl ions on meat proteins.

b. Effect on Meat Shrinkage

Data in Figure 3 demonstrates the synergistic effects of salt and phosphate additions to beef muscles. Meat shrinkage is reduced approximately 12% by the addition of 1% NaCl and 0.5% TPP after 180 minutes of heating.

D. Combined Effect of Different Phosphates

The recent approval of the use of TPP and HMP by the USDA in cooked beef (USDA, 1970) led to the testing of these two phosphates in various combinations on the water holding capacity of beef. Muscles selected for this study were the semimembranosus, longissimus and triceps brachii of a USDA Commercial grade carcass of chilled beef. The ground meat samples, with and without 1% NaCl, were used for the shrink determination at 70 ^{o}C.

Results and Discussion

The data in Figure 4 show that 0.3% TPP and 0.1% HMP, when used with 1.0% NaCl, resulted in the greatest reduction in shrink for these muscles. As the amount of HMP in the phosphate mixture added to the meat increases, the shrink increases. In samples without the NaCl, the increase of shrink is also noted as concentration of HMP in the phosphate mixture is increased. In both instances, the longissimus muscle gave the greatest shrinkage (the lowest water holding capacity) during the heating at 70 ^{o}C.

E. Effect of NaCl and TPP on Sensory Properties of Irradiated Cooked Meats

The effect of additive levels in pork and chicken has been reported by Shults, et al. (1976, 1977). It was found that significant differences were found in the sensory characteristics and shear press values between samples with and without NaCl and phosphate additions. In both the pork and chicken, additions of up to 1.5% NaCl and 0.5% TPP were acceptable and ratings were not significantly different from addition levels of 0.75% NaCl, 0.3% TPP or 0.5% NaCl with 0.5% TPP. Data from studies on meat swelling and water holding capacity showed that 0.3% TPP yielded the maximum

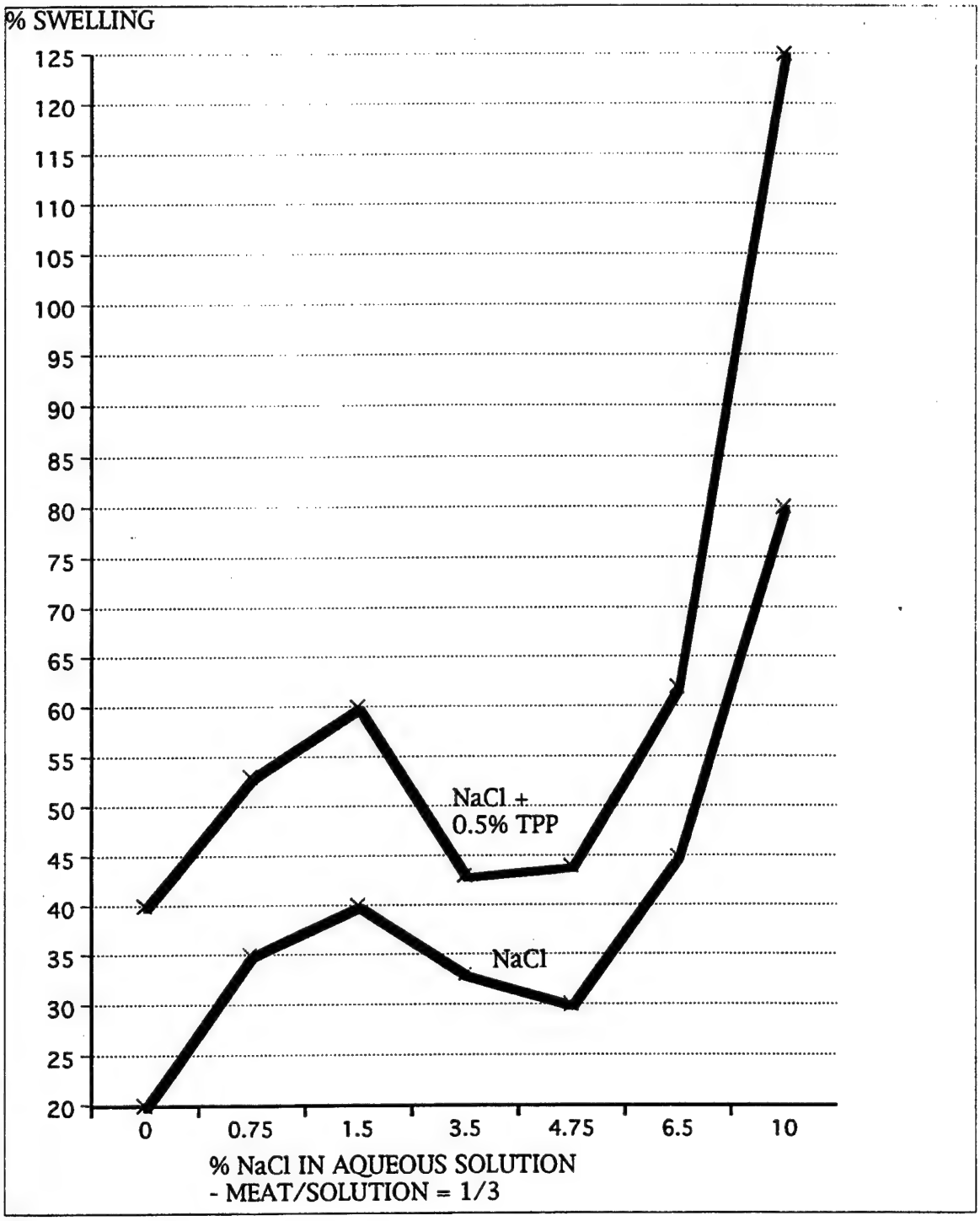

FIG. 2 - PERCENT SWELLING AS A FUNCTION OF PERCENT NaCl IN BEEF

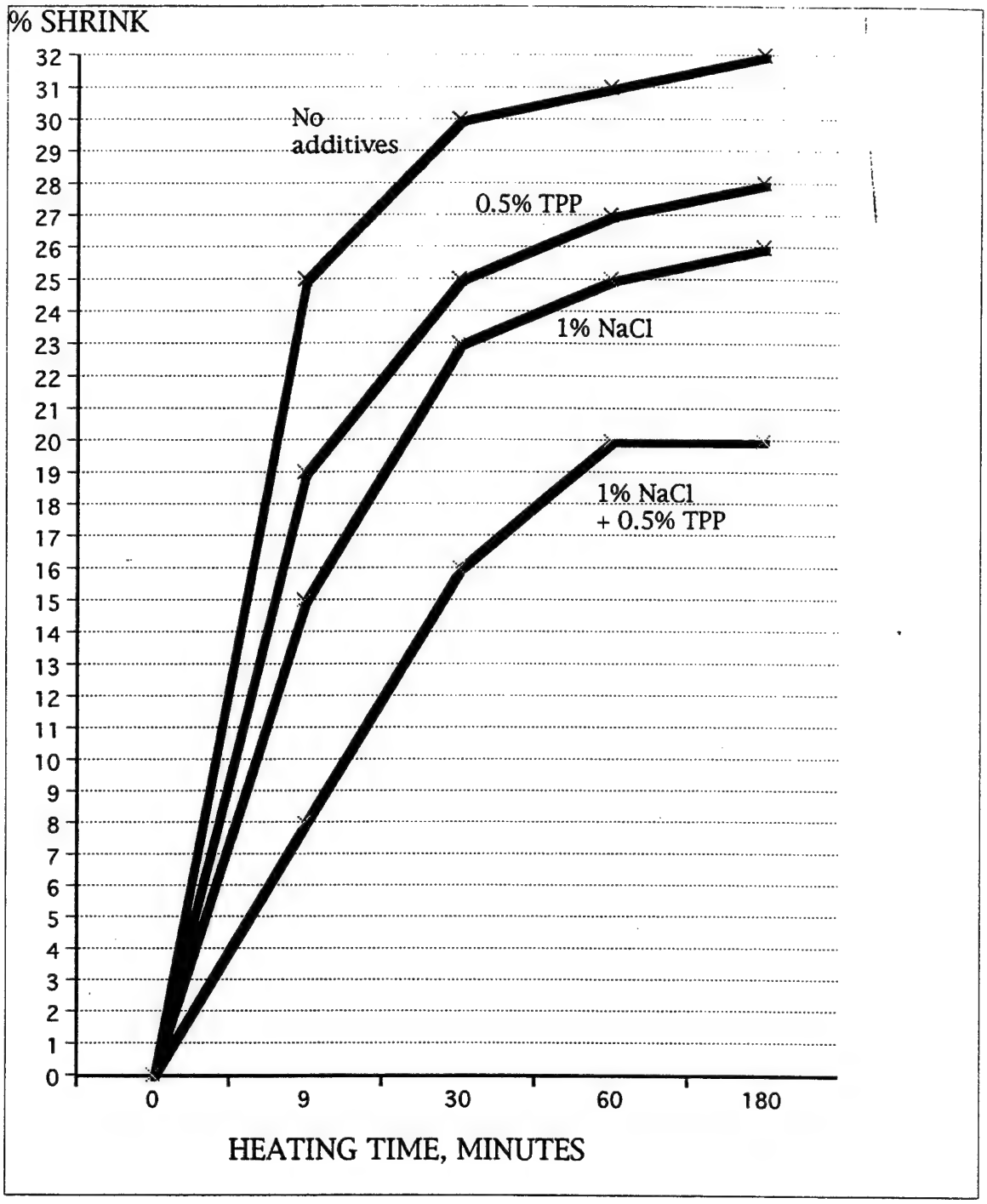

FIG. 3 - PERCENT SHRINK IN BEEF
AS FUNCTION OF NaCl AND HEATING TIME

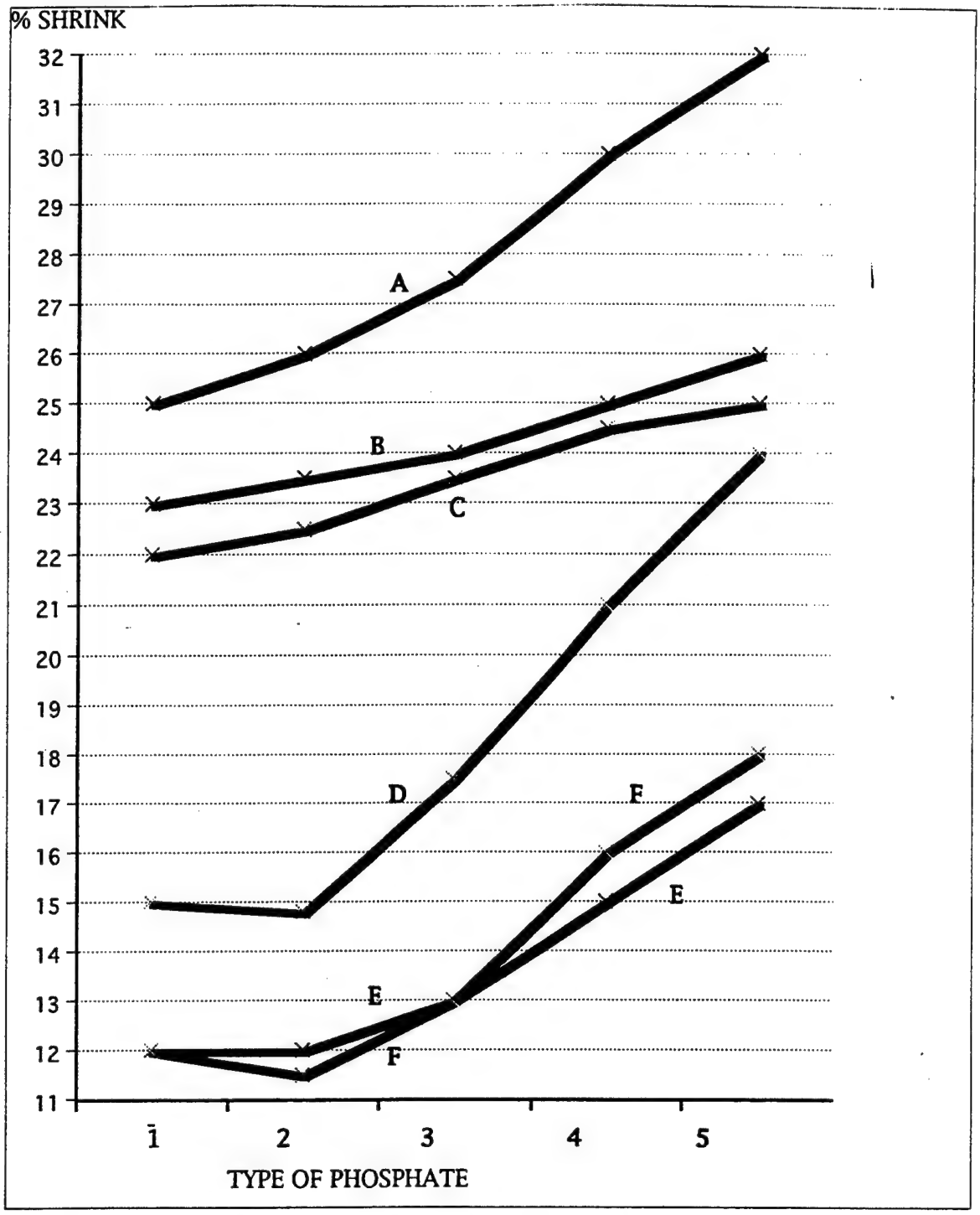

Fig. 4 - PERCENT SHRINK IN BEEF AS A FUNCTION OF PERCENT AND TYPE OF PHOSPHATE

A. l. dorsi, no NaCl
B. t. brachii, no NaCl
C. s. membranosus, no NaCl
D. l. dorsi, 1% NaCl
E. t. brachii,, 1% NaCl
F. s. membranosus, 1% NaCl

	% TPP	% HMP
1.	0.4	0.0
2.	0.3	0.1
3.	0.2	0.2
4.	0.1	0.3
5.	0.0	0.4

benefits in reducing cooking losses.

Table 14 shows the technological panel results on beef rolls prepared with 0, 0.5, 0.75 and 1.0% addition levels of NaCl and 0 or 0.5% levels of TPP. No significant differences were detected in the sensory characteristics of the irradiated samples.

Table 14 - Effect of NaCl on the Sensory Characteristics of of Irradiated Cooked Beef Rolls

Storage Time	NaCl	TPP	Sensory Characteristics									
			Discoloration		Off Odor		Irrad. Flavor		Off-Flavor		Mushiness	
months	%	%	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
0	0.00	0.0*	2.1	0.8	1.6	0.5	1.4	0.5	1.6	1.0	2.0	1.3
0	0.50	0.5*	2.0	0.7	1.6	0.7	1.5	0.7	1.4	0.5	1.8	0.8
0	0.75	0.5*	1.9	0.8	1.8	0.7	1.6	1.0	1.4	0.5	2.1	0.9
0	1.00	0.5*	1.6	0.7	1.9	0.8	2.0	1.3	1.1	0.3	1.8	1.0
0	0.00	0.0**	1.3	0.4	1.1	0.3	1.0	0.0	1.0	1.0	1.8	1.1
1	0.00	0.0*	2.1	0.6	1.6	0.5	2.6	0.7	2.4	0.9	2.7	1.3
1	0.50	0.5*	1.9	0.8	1.4	0.5	1.7	0.7	1.7	0.5	2.0	0.5
1	0.75	0.5*	1.0	0.0	1.1	0.4	1.3	0.5	1.4	0.5	1.6	0.5
1	1.00	0.5*	1.3	0.5	1.3	0.5	1.7	0.9	1.4	0.5	2.0	0.5
1	0.00	0.0**	1.1	0.4	1.3	0.5	2.0	0.8	1.9	0.6	2.9	0.6
3	0.00	0.0*	1.9	0.6	2.5	0.7	2.9	1.4	1.6	1.0	2.3	0.7
3	0.50	0.5*	3.1	1.8	2.4	1.2	2.5	1.9	2.0	1.0	2.8	1.4
3	0.75	0.5*	2.1	0.9	2.8	1.3	3.0	1.4	1.4	0.7	2.6	0.7
3	1.00	0.5*	2.6	1.0	2.0	1.0	2.4	1.1	1.6	1.0	2.9	1.4
3	0.00	0.0**	1.6	1.1	1.8	1,6	1.0	0.0	1.6	0.9	1.0	0.0
6	0.00	0.0*	2.0	1.1	3.0	1.8	3.7	2.5	2.6	2.3	3.0	1.9
6	0.50	0.5*	2.3	1.4	2.4	0.7	3.9	1.6	2.9	2.0	1.6	0.7
6	0.75	0.5*	2.3	1.0	2.6	1.1	3.0	1.7	1.9	0.8	3.1	1.6
6	1.00	0.5*	2.0	0.8	2.4	1.4	2.6	1.3	1.3	0.5	2.1	1.1
6	0.00	0.0**	1.1	0.4	1.7	1.4	1.1	0.4	2.1	0.4	1.0	0.0

* Irradiated - 47 to 56 kGy dose at -30 ± 10 °C ** Non-irradiated

7 to 8 panelists per test

Preference results in Table 15 show that the beef rolls without the additives rated unacceptable or borderline acceptability after 1 month of storage. The samples with 0.5% TPP and 0.5% NaCl were found unacceptable after 3 and 6 months of storage. The samples with 0.75 or 1.0% NaCl and 0.5% TPP consistently rated very acceptable. (The storage temperature was assumed to be 21 °C.)

Table 15 - Effect of NaCl and TPP on the Preference Ratings of Beef Rolls

		Preference Ratings after Storage Time, Months							
		0		1		3		6	
% NaCl	% TPP	mean	SD	mean	SD	mean	SD	mean	SD
0.00	0.0*	5.8	1.0	5.0	0.8	4.9	1.2	5.1	1.9
0.50	0.5*	5.9	0.6	6.0	0.8	4.0	1.2	4.7	1.9
0.75	0.5*	6.3	1.0	6.7	0.5	5.1	1.1	5.6	0.7
1.00	0.5*	6.0	1.1	6.1	0.6	5.9	0.8	5.9	0.9
0.00	0.0	6.9	1.1	5.9	1.0	6.9	0.8	6.4	1.9

* Non-irradiated, 7 to 8 panelists per test Irradiation conditions - 47 to 56 kGy at -30 ± 10 °C

Samples of beef rolls were prepared with 0.75% NaCl and 0.3% TPP and irradiated at the 12-D sterilizing doses of 47 kGy at -30 °C and 57 kGy at -80 °C. Table 16 shows the results of technological panels on the samples. No significant differences were found, but samples without the additives were consistently rated higher in intensities of discoloration, irradiation flavor and mushiness. This was reflected in the preference ratings which were lower for the samples without the additives. (The storage temperature was assumed to be 21 °C.)

Table 16 - Effect of Additives on the Quality of Beef Rolls

Storage Time	Additive		Dose	Intensity Rating								Hedonic Rating	
				Dis-Color		Off-Odor		Irrad. Flavor		Mushiness		Preference	
months	% NaCl	% TPP	Dose kGy	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
0	0.75	0.3	47	2.1	1.1	1.3	0.7	2.1	1.0	2.3	1.0	5.9	1.3
0	0.00	0.0	47	1.1	0.4	1.6	0.9	1.9	1.0	2.4	1.2	6.6	1.4
0	0.75	0.3	57	1.6	0.7	1.3	0.7	2.6	1.7	2.3	1.0	6.4	1.2
0	0.00	0.0	57	2.0	1.1	1.3	0.5	2.0	1.2	2.1	1.0	6.0	1.6
1	0.75	0.3	47	2.9	0.8	2.1	1.0	2.3	1.0	1.6	0.7	5.4	1.1
1	0.00	0.0	47	3.1	1.8	2.3	0.9	2.7	0.9	2.0	1.2	4.9	1.1
1	0.75	0.3	57	2.4	1.2	2.6	1.1	2.7	1.9	2.1	1.4	5.6	1.4
1	0.00	0.0	57	2.9	0.8	2.7	0.9	2.9	1.6	2.6	1.2	3.9	0.8
6	0.75	0.3	47	2.9	1.6	3.0	1.4	2.7	1.6	2.4	1.4	5.6	0.9
6	0.00	0.0	47	3.1	1.0	3,0	0.9	3.1	1.1	3.0	1.5	4.9	0.6
6	0.75	0.3	57	2.0	0.8	2.0	0.5	2.0	0.5	2.0	0.8	6.1	0.8
6	0.00	0.0	57	2.6	0.9	2.0	1.1	2.3	1.4	3.0	1.5	5.3	1.0

Consumer panel ratings for these samples are shown in Table 17. After one month of storage the samples with the additives rated higher than samples without additives at both dose levels. After three months of storage, the samples with additives were rated significantly higher (0.05 level) than the samples without the additives.

Table 17 - Effect of Additives on the Preference Ratings of Beef Rolls

% NaCl	% TPP	Dose kGy	Ratings after Months of Storage 1	3
0.75	0.3	47	6.7[a]	6.6[b]
0.00	0.0	47	6.2[a]	6.4[c]
0.75	0.3	57	7.1[a]	7.2[b]
0.0	0.0	57	5.9	6.4[c]

Numbers followed by the same letter are not significantly different (0.05 level)

Irradiation temperature - -30 ± 10 °C
32 panelists per test

These results point out the advantage of including NaCl and TPP in the formulation of beef rolls. The additive level of 0.75% NaCl and 0.3% TPP was selected for the formulation of the beef rolls used in the wholesomeness feeding studies on beef, supporting petitions for clearance by the FDA for human consumption.

The research that resulted in the development of sectioned and formed beef rolls with salt and phosphate contributing to the binding mechanisms allowed the production of a product that would hold together after irradiation processing and be acceptable. However, the 12-D doses of 47 kGy at -30 °C and 57 kGy at -80 °C were determined using whole beef rounds without the additives. A microbiological study was conducted to determine a 12-D dose for beef rolls made from the whole carcass and containing 0.75% NaCl and 0.3% TPP. Results showed the 12-D dose to be 37 kGy at -30 °C, 10 kGy lower than without the additive.

To compare the quality of beef rolls irradiated at the three doses, a study was initiated using beef rolls processed according to specification stated in the protocol for the wholesomeness testing of beef.

Total organic reducing volatiles were determined using steam distillation for organic volatiles into an alkaline permanganate solution. Results in Table 18 are expressed as milliequivalents of oxygen per 100 g of meat. A significant difference was found between 37 and 47 kGy dose levels. No differences were obtained between the 47 and 57 kGy dose levels, which were done at different temperatures.

Table 18 - Total Organic Volatiles (ORV) for Beef Rolls

Dose kGy	Irrad. Temp. °C	pH	ORV meq oxygen per 100 g meat mean	SD
*	-30	6.0	8.2	0.4
37	-30	6.0	10.5	0.9
47	-30	6.0	12.2[a]	0.9
57	-80	6.0	12.3[a]	0.4

* Non-irradiated control
Numbers followed by the same letter are not significantly different (0.01 level)

Textural determinations were made using a Kramer™ shear device The results in Table 19 show that no differences were found between the 37 and 47 kGy dose levels, at -30 °C. However, samples irradiated at 57 kGy and -80 °C were found to be tougher, indicating that the lower temperature decreased the tenderness due to irradiation.

Consumer panel ratings are shown in Table 20. After 3 months of storage, no significant differences were found and all the samples rated acceptable.

Technological panel ratings are shown in Table 21. No significant differences were found by technological panels after 6 months of storage.

Table 19 - Shear Press Values for Beef Rolls

Dose kGy	Irradiation Temp. °C	Shear Press Readings Newtons	
		mean	SD
37	-30	99[a]	7.0
47	-30	98[a]	7.4
57	-80	103	5.7
Frozen Control		108	6.7

Numbers followed by the same letter are not significantly different (0.05 level)

Table 20 - Consumer Panel Ratings for Irradiated Beef Rolls

Dose kGy	Irradiation Temp. °C	Preference Rating after Storage 1 month		3 months	
		mean	SD	mean	SD
37	-30	5.9[a]	1.8	6.7[c]	1.7
47	-30	5.7[a,b]	2.6	6.7[c]	1.7
57	-80	6.4[b]	1.2	6.3[c]	1.6

32 member panel

Numbers followed by the same letter are not significantly different (0.05 level)

Table 21 - Effect of 12-D Sterilizing Irradiation Dose on the Sensory Characteristics of Beef Rolls

Irradiation Dose kGy	Temp. °C	Intensity Rating Color	Odor	Flavor	Texture	Hedonic Rating Preference	Storage Time Months
37	-30	5.6	5.1	5.0	5.5	4.9	0
47	-30	5.6	5.2	5.6	6.1	5.2	0
57	-80	5.3	5.5	4.9	5.1	4.8	0
*		5.6	6.7	6.1	6.7	6.2	0
37	-30	6.4	5.8	5.8	6.4	5.6	1
47	-30	6.0	6.2	5.2	5.3	5.1	1
57	-80	6.4	6.1	5.2	5.3	5.1	1
*		6.3	6.3	5.9	6.4	5.7	1
37	-30	5.6	5.0	4.8	5.2	4.6	3
47	-30	5.8	5.1	4.4	5.1	4.7	3
57	-80	5.2	5.6	4.6	5.3	4.9	3
*		6.8	6.7	6.4	6.8	6.7	3
37	-30	5.8	5.4	4.8	4.9	5.0	6
47	-30	5.6	5.6	5.1	5.0	5.1	6
57	-80	5.5	5.1	4.9	4.1	5.0	6

* Frozen control

8 to 10 panelists per test No significant differences (0.05 level)

F. Effect of Textured Soy Protein (TSP)

Material

The ground beef patties were made from USDA Choice graded beef rounds consisting primarily of the semimembranosus, semitendinosus and biceps femoris muscles.

The soy products tested were Ral-Con™, Ral-Con Foods, Inc.™, Patti-Pro™, Promate™, I11™, GL301™ and Vegamine™ (hydrolyzed vegetable protein) all products of Griffith Laboratories; Temptein™ and Pro-Lean 4T™ manufactured by Miles Laboratories. The TSP was added in either a dry form or rehydrated in water to the appropriate water content, depending upon the individual TSP properties. The TSP was rehydrated by soaking for two hours in cold water at 15 $\pm$ 2 °C and then drained prior to addition to the meat.

The phosphates studied were TPP, PP, HMP, Foodfos™, Curafos 11-2™ and Curafos 22-4™, commercial combinations of HNP and TPP and Kena™, (a commercial combination of PP, TPP and sodium acid pyrophosphate). These phosphates were obtained from the Merck Chemical Co.

Processing

The beef rounds (7 to 10 days postmortem) were trimmed to approximately 5% fat and ground through a 13 mm grinding plate with enough fat to approximate the desired fat levels. The ground meat was then mixed with the additives and 3% crushed ice in a mixer (Hobart Model No. H-600-D™) for 3 minutes at a moderate speed and then formed into patties of the desired mass and shape for enzyme inactivation.

For the final series of experiments, the USDA Choice beef rounds were trimmed in the same manner. The meat with the added fat was ground through a 13 mm plate. This ground beef was mixed with 3% ground ice and the additives for one minute at low speed in the Hobart™ mixer.

The patties were broiled in a 250 $\pm$ 15 °C oven for eight minutes on one side, turned over and broiled for another three minutes. The internal temperature of the patties was 75 $\pm$ 2 °C. The patties were then weighed to measure the moisture loss on cooking.

Packaging

The ground beef patties were packed in 404 x 309 cans with epoxyphenolic meat enamel and sealed under a pressure of 7 $\pm$ 1 kPa. They were then held at -40 $\pm$ 2 °C until irradiation processing.

Irradiation Processing

Irradiation was performed with a Co^{60} source at a dose rate of 12 kGy/sec. Irradiation conditions were: Dose of 37 to 43 kGy at a temperature of -30 $\pm$ 10 °C. After irradiation, the samples were thawed and held at 21 $\pm$ 2 °C until evaluation. The nonirradiated sample controls were held at -20 $\pm$ 2 °C.

Methods

a. Texture Evaluation

Kramer Shear Press™ analyses were performed on all samples within 3 days of irradiation. This method is described by Cohen, et al. (1974) with the following modification: A single blade shear cell was used with the 136 kg ring and the "3-0" (100%) scale. The beef patty was cut so that the blade penetrated a cross section,

13 ± 1 mm deep by 24 ± 1 mm wide. Sixteen replications were performed on each sample. The samples were analyzed at a temperature of + 4 ± 1 °C. The results are reported in Newtons.

b. Chemical Analysis

Proximate analysis for the beef patties were determined using standard AOAC techniques (AOAC, 1970).

c. Percent Meat Swelling

The meat swelling (water-binding capacity) was determined by the method of Wierbicki, et al. (1982) previously described in this paper.

Results and Discussion

a. Effect of TSP on Swelling

Many investigators have studied the effects of fat level on the acceptance of ground beef patties (Glover, 1964; Cole, et al., 1960, Kendall, et al., 1974). The fat levels studied ranged from 10 to 35%. Three levels of fat were chosen, 10.8, 16.8 and 20.6%, which are approximately the fat levels available commercially. TSP levels used were 10 and 20%. Only two TSP samples were investigated in this study, Ral-Con™ and Pro-Lean™, and were chosen because of their dissimilarity.

Ral-Con™ is a spun protein which has its fibers in bundles and contains approximately 35% moisture, whereas Pro-Lean™ is a granulated, dry type of protein with a moisture content of 2%.

Table 22 lists the results on cooking losses and shear press value of samples with 10 and 20% TSP (Ral-Con™) at two fat levels (10 and 30%). Significant differences in cooking losses were found between 10 and 30% fat levels. No significant differences were found in cooking losses between 10 and 20% TSP addition. Significant differences were not found for shear press values; however, the 30% fat levels had lower shear values.

Table 22 - Effect of TSP and Fat on Cooking Loss and Kramer Shear Press Values

TSP %	Fat %	Cooking Loss %	Kramer Shear Values (Newtons) Irradiated	Nonirradiated
10	10	11.6	46.5	56.1
10	30	21.4	38.4	47.4
20	10	15.0	49.9	55.9
20	30	25.5	46.5	54.2

Cooking Loss - F = 51 (0.01 level), LSD (0.05) = 5.5; LSD (0.01) = 7.4
Kramer Shear Press - F = 3.2 (0.01 level), LSD (0.05 = 14.5, LSD (0.01) = 19.3

F = 1.9 (NSD) for unirradiated samples
F = 1.8 (NSD) for irradiated samples (37 to 43 kGy)

b. Effect on Sensory Scores

A technological panel (Table 23) found no significant differences in the cooked samples with 10 and 30% fat, also in the 10 and 20% TSP addition levels. The nonirradiated samples were again rated higher than the irradiated samples.

Table 23 - Effect of TSP and Fat on Sensory Scores

% NaCl	% TPP	% TSP	% Fat	Sensory Scores: Color mean	Color SD	Odor mean	Odor SD	Flavor mean	Flavor SD	Texture mean	Texture SD	Appear. mean	Appear. SD	Preference Rating mean	Preference Rating SD
A. Unirradiated															
1.0	0.5	10	10	6.7	1.1	7.0	1.1	6.9	0.8	6.7	1.2	6.8	1.2	6.7	1.3
1.0	0.5	10	30	6.6	0.9	6.7	0.8	6.3	1.1	6.2	1.5	6.3	1.5	6.1	1.2
1.0	0.5	20	10	6.7	1.1	6.8	0.9	6.8	0.9	6.3	1.0	6.5	0.9	6.5	0.5
1.0	0.5	20	30	6.2	1.3	6.8	0.8	6.5	1.1	6.5	1.0	6.3	1.7	6.3	1.0
B. Irradiated (37 to 43 kGy)															
1.0	0.5	10	10	6.3	1.6	5.9	1.6	5.9	1.7	5.2	2.0	5.5	1.7	5.1	2.4
1.0	0.5	10	30	5.8	1.1	6.1	1.8	5.1	1.2	5.4	1.4	5.3	1.3	5.2	1.1
1.0	0.5	20	10	6.5	1.5	5.8	1.3	5.4	1.8	5.2	2.0	5.6	1.2	5.0	1.7
1.0	0.5	20	30	6.3	0.8	5.5	1.5	5.2	1.1	5.6	1.7	5.5	1.3	5.2	1.8

Samples grouped together were tested at the same time
No significant differences on any test (0.05 level)

c. Effect on Swelling

The rehydration of the TSP samples was accomplished by soaking for two hours at +2 to - 5 °C. The 2% moisture Pro-lean™ samples had more swelling than the 35% moisture Ral-Con™ samples for each of the fat and TSP levels as shown in Table 24.

Table 24 - Effect of Fat and TSP Content on Percent Swelling

% TSP	Rehydrated	TSP Type	% Swelling at % Fat: 10	20	30
0	NA	none	143	126	137
10	no	Pro-lean™	169	169	137
20	no	Pro-lean	131	117	111
30	no	Pro-lean	134	149	111
10	yes	Pro-lean	131	123	100
20	yes	Pro-lean	131	118	91
30	yes	Pro-lean	111	97	91
10	no	Ral-Con™	149	117	130
20	no	Ral-Con	103	120	77
30	no	Ral-Con	114	94	91
10	yes	Ral-Con	126	103	77
20	yes	Ral-Con	114	91	60
30	yes	Ral-Con	109	89	60

G. Effect of NaCl, Phosphate and Fat Content

The effect of TPP (0 and 0.3%) and NaCl (0 and 0.75%) were used to test the effects of fat levels (25.8 and 7.8%) in irradiated and nonirradiated beef patties.

Results and Discussion

a. Cooking Loss and Shear Values

Table 25 lists the levels of salt, phosphate and fat used in this experiment and their effect on the cooking loss and Kramer shear values. Fat, salt and phosphate

showed no differences for cooking losses. Salt decreased the Kramer shear values except for the nonirradiated samples with 7.8% fat; increased fat did the same for the nonirradiated product, but not for the irradiated product; phosphate had no effect on these values.

Table 25 - Effect of Salt, Phosphates and Fat Content on Cooking Loss and Shear Press Values

% NaCl	% TPP	% Fat	Cooking Loss, %	Shear Values (Newtons)	
				Irradiated	Nonirradiated
0.00	0.0	25.8	30.3	51	47
0.75	0.0	25.8	35.4	24	25
0.00	0.3	25.8	34.2	35	48
0.75	0.3	25.8	29.5	32	41
0.00	0.0	7.8	28.4	44	56
0.75	0.0	7.8	29.8	36	62
0.00	0.3	7.8	30.4	40	61
0.75	0.3	7.8	24.8	26	49

All samples were double ground through a 5 mm plate
For Shear Values Irradiated - F = 7.9 (0.01 significance), lsd (0.05) - 18.8
LSD (0.01) - 25.4

Nonirradiated - F = 5.3 (0.01 significance); lsd (0.05) - 17.4
LSD (0.01) - 23.2

For Cooking Loss: F = 11.1 (0.01 significance; lsd (0.05) - 5.8, lsd (0.01) - 7.7

b. Sensory Scores

Table 26 shows the sensory scores for this experiment. All the samples were rated acceptable, with the patties without the additives rating numerically lower. The differences, however, were not found to be significant.

Table 26 - Effect of Fat, NaCl and TPP on Sensory Scores

Fat	NaCl	TPP	Sensory Ratings										Preference	
			Color		Odor		Flavor		Texture		Appear.		Rating	
%	%	%	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
A. Irradiated														
25.8	0.00	0.0	6.8	1.1	6.4	0.9	5.4	1.3	6.2	1.3	6.8	0.9	5.3	1.5
25.8	0.75	0.0	6.8	1.0	6.3	1.1	6.8	0.8	6.8	1.1	7.1	0.5	6.5	0.9
25.8	0.00	0.3	6.7	0.8	6.3	0.5	6.1	1.2	6.4	0.8	6.7	0.7	5.9	1.4
25.8	0.75	0.3	6.2	1.2	6.3	0.9	5.8	1.5	6.3	1.5	6.8	0.6	5.8	1.5
7.8	0.00	0.0	6.5	1.2	6.1	1.2	4.5	1.9	6.1	1.3	6.6	1.2	5.1	1.4
7.8	0.75	0.0	6.3	1.4	6.0	1.6	5.1	1.9	6.4	1.2	6.4	1.1	5.3	1.7
7.8	0.00	0.3	6.3	0.9	6.0	0.9	5.6	1.4	6.1	1.2	6.1	1.2	5.8	1.4
7.8	0.75	0.3	6.7	1.1	6.2	1.0	5.5	1.4	6.2	1.1	6.4	0.9	5.6	1.5
B. Nonirradiated														
25.8	0.00	0.0	6.7	0.5	6.8	0.9	6.1	1.4	6.3	1.1	6.7	1.0	6.2	1.5
25.8	0.75	0.0	7.1	0.8	6.9	0.5	7.2	1.1	7.0	0.9	7.3	0.9	7.3	0.8
25.8	0.00	0.3	7.0	0.7	6.9	0.9	6.4	1.4	6.6	1.2	6.8	0.8	6.4	1.6
25.8	0.75	0.3	7.3	0.5	7.1	0.5	6.8	0.8	7.0	0.6	7.3	0.7	6.9	1.4
7.8	0.00	0.0	6.7	0.8	6.7	0.8	6.3	1.0	6.2	1.3	6.6	0.8	6.3	1.1
7.8	0.75	0.0	6.6	0.9	6.8	1.2	6.5	1.7	6.9	0.9	6.6	1.1	6.7	1.4
7.8	0.00	0.3	6.8	0.8	6.8	0.8	6.1	1.0	6.6	0.9	6.8	0.8	6.2	0.7
7.8	0.75	0.3	7.1	0.5	6.8	1.1	6.1	2.1	7.1	0.5	7.3	0.8	6.4	2.1

No significant differences for any test.
All samples double ground 5 mm plate

The results of these studies have demonstrated that acceptable, shelf-stable irradiated ground beef patties can be produced. It can be concluded that the fat level and degree of grind does not affect product quality. The use of NaCl and phosphates is beneficial in reducing cooking losses and in textural improvements. Irradiation at sterilizing doses and the subsequent short-term storage at 21 $\pm$ 2 ^{o}C resulted in a lowering of the acceptance of the ground beef patties as compared to frozen controls

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H. Effect of Different Food Grade Phosphates on Beef Rolls

Table 27 lists the different food-grade phosphates evaluated at 0.375 addition level. The effects on the percent cooking loss and shear press values of irradiated beef rolls when used with and without 0.75% NaCl are shown.

Table 27 - Effect of Food Grade Phosphates on Cooking Loss and Shear Press Values

Type of Phosphate	% NaCl	Percent Loss	% Cooking Loss	Shear Values, Newtons	
			Irradiated	Non-irradiated	
PP	0.00	21	60	53	
PP	0.75	10	49	48	
TPP	0.00	21	48	59	
TPP	0.75	11	46	62	
11-2	0.00	24	51	55	
11-2	0.75	14	49	52	
22-4	0.00	20	52	63	
22-4	0.75	13	53	57	
Kena	0.00	23	58	59	
Kena	0.75	14	52	49	
HMP	0.00	19	46	72	
HMP	0.75	17	42	73	
Foodfos	0.00	25	55	69	
Foodfos	0.75	21	46	60	
none	0.00	25	75	71	
none	0.75	19	50	58	

Data Analysis

Cooking Loss - F = 46 (0.01 significance)
LSD (0.05) - 1.6; LSD (.01) - 2.4
Samples with no salt - F = 11.1 (0.01 significance
LSD (0.05 - 2.3; LSD (0.01) -3.1
Samples with salt - F = 44 (0.01 significance)
LSD (0.05) - 2.0; LSD (0.01) - 2.8

Shear values (nonirradiated)
F = 2.2 (0.01 significance)
LSD (0.05) - 1.2; LSD (0.01) - 1.6
Samples with no salt - F = 2.9 (0.01 significance)
LSD (0.05 - 7.1); LSD (0.01) - 9.7
Samples with salt - F = 4.1 (0.01 significance
LSD (0.05) - 20.9; LSD(0.01) -28.3

Shear values (irradiated)
F = 7.6 (0.01 significance
lsd (0.05) - 8.5; lsd (0.01) - 11.5
Samples with no salt - F = 1.6 NSD
Samples with salt - F = 0.9 NSD

The most effective phosphate for moisture retention, particularly in the presence of NaCl, was PP, followed by TPP. Both PP and TPP were significantly more effective than the other phosphates. Cooking losses were reduced from 25% with no additive to 10% with 0.75% NaCl and 0.375% PP. The use of PP with no NaCl resulted in only a 4% reduction in cooking loss. These results demonstrate the synergistic effects of Phosphate and NaCl on water retention as reported by Mahan, 1961. The use of TPP with 0.75% NaCl gave similar results as PP.

In this experiment, and all others in this study, irradiation of the samples generally decreased the shear values as compared to the corresponding nonirradiated samples.

The addition of NaCl decreased the cooking loss and the shear values for both irradiated and nonirradiated samples. No significant differences were found between values for the two groups.

Sensory tests were not done with this experiment. Earlier work on other beef products demonstrated no sensory differences in the use of these phosphates.

I. Irradiated Corned Beef Product

The development of an irradiated corned beef product was similar to the work on ham (Wierbicki, 1974, 1975). The research on ham had shown that the level of nitrate and nitrite additions could be reduced to minimum levels without adverse effects on product quality.

The research on corned beef was initiated to determine the minimal levels of nitrate and nitrite additions and to determine the additive level effects on color and preference ratings.

Material

The raw material used in this study was fresh, 7 to 10 day post mortem, beef briskets excised from USDA Choice carcasses. The briskets were trimmed of all exterior fat prior to curing. The briskets were pumped to a 15% added mass with curing solutions containing the various additive levels. All the cures contained 3.0% NaCl, 275 ppm sodium ascorbate and 275 ppm sodium erythorbate. Sodium nitrate levels were 0, 100 and 600 ppm. Sodium nitrite levels were 0, 25 and 150 ppm. The briskets were held for 72 hours at +2 to +5 ^{o}C after pumping.

The cured briskets were cooked in a water kettle at 96 to 98 ^{o}C until an internal temperature of 80 $\pm$ 2 ^{o}C was reached, and then simmered at 75 ^{o}C for an additional hour. After cooking, the briskets were cooled overnight at +2 to +5 ^{o}C.

Methods

a. Packaging

The cooked briskets were cut into portions and packed in 404 x 309 cans with epoxy phenol type of interior enamel, and closed under a pressure of 7 $\pm$ 1 kPa. A weight of 596 $\pm$ 10 g was packed into each can. After closure, the cans were frozen to -40 $\pm$ 5 ^{o}C prior to irradiation.

b. Irradiation Processing

Irradiation of the corned beef samples was accomplished in the Co^{60} source at Natick. Samples of the dose effect study received minimum doses of 25, 35 and 45 kGy. The dose range was the minimum dose + 18 %. Other samples received a dose of 25 to 33 kGy. The dose rate was 12 Gy/sec. Temperatures during irradiation were controlled at 0, -30, or -80 $\pm$ 10 ^{o}C using liquid nitrogen. The samples were stored at either 21 or 38 $\pm$ 2 ^{o}C after irradiation. The nonirradiated samples were stored at -29 ^{o}C until evaluation.

c. Reflectance

The reflectance in three color ranges (red, green and blue) was determined using a tristimulus color meter (Photonic™) with the instrument calibrated at 90% reflectance. Fourteen replications per variable were taken and the results reported as percent reflectance.

d. Thiobarbituric Acid (TBA)

TBA values were determined with the method of Tarladgis, et al. (1960).

Results and Discussion

a. TBA Values

Table 28 lists the results of the storage test of cooked corned beef briskets sliced and packaged in open cans. The results indicate that all samples had very low TBA values, far below the 10 mg malonaldehyde per kg meat required for organoleptic detection of rancidity . The sample with 600 ppm $NaNO_3$ and 150 ppm $NaNO_2$ did not show any increase in TBA values over the four weeks of storage. The samples with the 25 ppm $NaNO_2$ had low TBA values for the first two weeks of storage, but after three weeks, the TBA values increased to the levels found in the samples with 100 ppm $NaNO_3$, and no $NaNO_3$ and $NaNO_2$. The addition of 25 ppm $NaNO_2$ to corned beef will allow refrigerated storage of the cooked corned beef for one to two weeks prior to packaging for irradiation processing, without any increase in TBA value.

Table 28 - Effect of Storage on TBA Values of Corned Beef Brisket

$NaNO_2$	$NaNO_3$	TBA Values after Weeks of Storage*			
ppm	ppm	mg malonaldehyde per kg meat			
		1	2	3	4
150	600	0.05	0.05	0.07	0.09
25	100	0.04	0.16	0.52	0.60
25	0	0.06	0.17	0.37	0.45
0	100	0.21	0.42	0.39	0.47
0	0	0.30	0.45	0.29	0.62

* Storage at 0 to + 5 ^{o}C

b. Sensory

Sensory evaluations of the irradiated samples were made at one and four weeks of storage at 21 $\pm$ 2^{o}C. Sensory ratings (Table 29) of the samples with 100 ppm $NaNO_3$ and no $NaNO_2$ or $NaNO_3$ were generally lower than the other samples. The sample with no $NaNO_3$ and no $NaNO_2$ was significantly lower in color and appearance than the other samples. The sample with no $NaNO_2$ and $NaNO_3$ was rated acceptable and not significantly different from samples with added 600/150 and 100/25 ppm $NaNO_3/NaNO_2$ for all the sensory characteristics, except for color at one week. As the level of the $NaNO_3$ and $NaNO_2$ decreased, the color intensities also decreased. Similar results were reported on irradiated cured ham (Wierbicki and Heiligman, 1973 and Wierbicki, et al., 1974).

Table 29 - Effect of Sodium Nitrate and Sodium Nitrite Addition on the Sensory Quality of Corned Beef

Additive		Sensory Scores after Weeks of Storage									
$NaNO_2$	$NaNO_3$	Color		Odor		Flavor		Texture		Appearance	
ppm	ppm	1	4	1	4	1	4	1	4	1	4
150	600	8.0	7.6[c]	7.3	6.5	6.8	6.0[e]	7.8	7.1	6.6	6.1[e]
25	100	7.5	7.4[c]	6.8	6.0	6.4	6.4[e]	6.8	6.8	6.5	6.5[e]
25	0	6.0[b]	6.5	6.3	6.0	6.5	6.3[e]	6.5	6.3	6.0	6.2[e]
0	100	4.1[a]	5.1	6.1	5.9	5.4	5.4	6.5	6.6	4.8[a]	5.4
0	0	3.5a	3.5d	5.5	5.6	5.3	4.8	5.9b	6.3	4.3a	4.3

a significantly different from the other samples (0.05 level)
b significantly different from the samples with 150 ppm $NaNO_2$ and 600 ppm $NaNO_3$ (0.05 level)
c significantly different from the samples with 0 $NaNO_2$ and 100 ppm $NaNO_3$ (0.05 level)
d significantly different from the other samples (0.05 level)
e significantly different from the sample with 0 $NaNO_2$ and 0 $NaNO_3$ (0.05 level)

12 panelists per test Irradiation conditions: 25 kGy at -30 ± 10 °C

In another experiment corned beef briskets were pumped with curing solutions containing (a) 600/150 ppm $NaNO_3/NaNO_2$;(b) 100/25 ppm $NaNO_3/NaNO_2$, the level proposed for irradiated ham; (c)150 ppm $NaNO_2$ only, the approximate level allowed by the USDA and; (d) 25 ppm $NaNO_2$.

Consumer panel preference ratings of the samples are listed in Table 30. Consumer panelists rated all the samples acceptable, but the sample with 150 ppm $NaNO_2$ was rated significantly lower than the samples with 600/150 ppm NaNO3/NaNO2 and the sample with 25 ppm $NaNO_2$.

Table 30 -Consumer Panel Evaluation of Irradiated Corned Beef

$NaNO_2$	$NaNO_3$	Preference Rating	
ppm	ppm	mean	SD
150	600	6.2[a]	2.0
25	100	6.0 [a,b]	1.7
150	0	5.5[b]	1.9
25	0	6.4[a]	1.3

Ratings followed by the same letter are not significantly different
32 panelists 30 days storage at room temperature
Irradiation conditions: 25 to 33 kGy at -30 ± 10 °C

c. Color

The color intensities (Table 31) of the samples were determined visually by 12 technologists. Ratings for color were at 0 and 2 hours exposure to ambient light. At 0 time exposure the samples with 25 ppm $NaNO_2$ was rated significantly different from 2 samples containing $NaNO_3$. The sample with 150 ppm $NaNO_2$ was not significantly different from the samples with the $NaNO_3$. After two hours exposure, the sample with 600/150 ppm $NaNO_3/NaNO_2$ was significantly different from the other samples. No differences were found between the sample with 100/25 ppm $NaNO_3/NaNO_2$ and the sample cured with 150 ppm $NaNO_2$. The results show a different trend in the color intensities with the lowering of the additive level. From these results it was ascertained that the addition of $NaNO_2$ to the curing solution was beneficial. However, an acceptable irradiated corned beef can be produced using only $NaNO_3$ as the curing additive.

Table 31 - Effect of $NaNO_2$ $NaNO_3$ Level on the Sensory Color of Irradiated Corned Beef

Additives		Sensory Color after Exposure Time			
$NaNO_2$	$NaNO_3$	0 hours		2 hours	
ppm	ppm	mean	SD	mean	SD
600	150	7.4[a]	1.0	7.8	0.6
100	25	7.0[a]	0.9	6.5[c]	0.8
0	150	6.7[a,b]	1.3	6.3[c]	1.3
0	25	5.8[b]	1.3	5.2	1.4

Ratings followed by the same letter are not significantly different

12 panelists per test Irradiation conditions: 25 to 33 kGy at -30 $\pm$ 10 ^{o}C

The reflectance values obtained with a tristimulus colorimeter are shown in Table 32. The percent reflectance for each of the samples tested in three ranges (red (640 nm), green (546 nm) and blue (436 nm)) show that at 0 and 2 hours exposure, no differences were found in the samples that could be attributed to the curing ingredients. All samples exhibited color fading after two hours exposure to light. The samples with 25 ppm $NaNO_2$ appears to have a higher degree of fading than the other samples.

Table 32 - Reflectance Values of the Color of Irradiated Corned Beef Briskets

Additive		Reflectance	Percent Reflectance after Exposure Time			
$NaNO_2$	$NaNO_3$	Color	0 hours		2 hours	
			mean	SD	mean	SD
150	600	red	53.8	6.7	50.7	2.6
150	600	green	14.5	1.3	11.4	1.6
150	600	blue	11.3	1.6	9.9	1.2
25	100	red	52.4	1.8	48.7	2.0
25	100	green	12.9	1.2	10.8	1.2
25	100	blue	9.1	1.3	9.3	1.1
150	0	red	55.9	1.3	50.9	3.3
150	0	green	13.7	1.3	11.9	0.9
150	0	blue	11.6	1.1	9.2	0.8
25	0	red	55.8	1.4	49.1	1.1
25	0	green	14.4	1.4	10.6	1.2
25	0	blue	14.2	1.1	8.4	0.8

14 replications per sample exposure to light at 21 ^{o}C

The chemical analyses of the irradiated corned beef briskets are shown in Table 33. The analyses were done according to standard AOAC procedures.

Table 33 - Chemical Analysis of Irradiated Corned Beef

Additives				Proximate Analysis				
$NaNO_2$		$NaNO_3$						
ppm		ppm		Percent	Percent	Percent	Percent	Percent
Goal	Actual	Goal	Actual	Moisture	Fat	Protein	Ash	NaCl
150	3.6	600	558	62.2	7.8	26.3	2.6	2.3
25	1.5	100	118	62.9	10.5	23.3	2.8	2.6
150	1.3	0	0	60.9	10.3	25.1	2.5	2.3
25	17	0	0.8	60.7	8.9	27.0	2.6	2.6

J. Acceptance of Irradiated Food

Schutz and Cardello, 1997 conducted a study to determine the effect of various methods of product information on the awareness and concerns of military personnel regarding irradiated foods and the willingness of military personnel to consume such foods. They determined that the most effective information treat ments was a video which raised their judged likelihoood to consume irradiated food. They concluded that positive, credible information about the safety and use of irradiated food can enhance acceptance. This study is mentioned here as it contains an extensive list of references that may be of interest.

This document reports research undertaken at the U.S. Army Soldie and Biological Chemical Command, Soldier Systems Center, and ha been assigned No. NATICK/TR-99/026 in a series of reports approved for publication.

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